(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 1 249 396 A1

(12) **EUROPEAN PATENT APPLICATION**
published in accordance with Art. 158(3) EPC

(43) Date of publication:
16.10.2002 Bulletin 2002/42

(21) Application number: **01981094.4**

(22) Date of filing: **13.11.2001**

(51) Int Cl.7: **B64G 1/38**, B64G 1/66, F16C 32/04

(86) International application number:
PCT/JP01/09911

(87) International publication number:
WO 02/042154 (30.05.2002 Gazette 2002/22)

(84) Designated Contracting States:
AT BE CH CY DE DK ES FI FR GB GR IE IT LI LU MC NL PT SE TR

(30) Priority: **22.11.2000 JP 2000356518**
08.12.2000 JP 2000374362
05.09.2001 JP 2001269398
06.09.2001 JP 2001270448

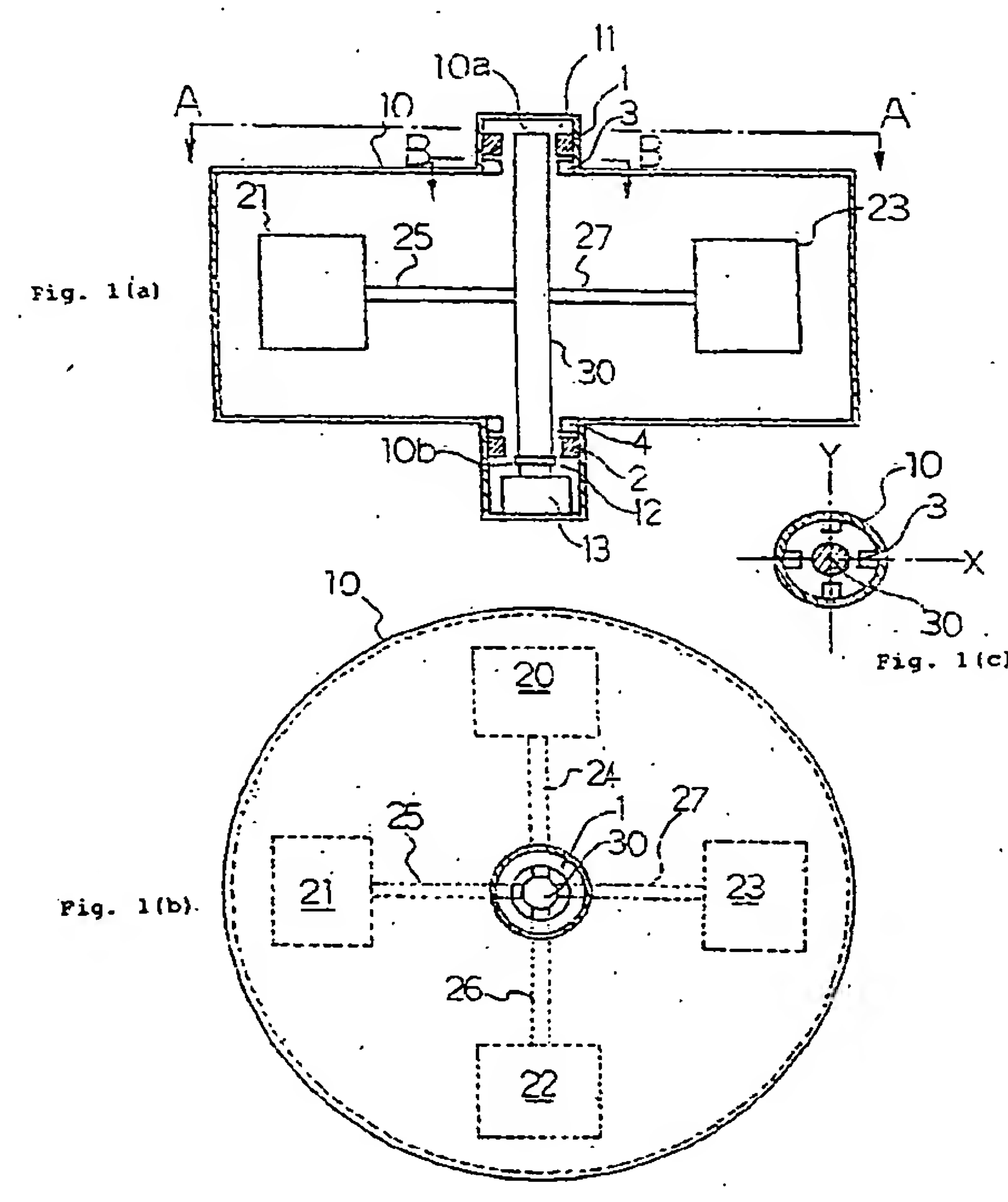
(71) Applicant: **Mitsubishi Heavy Industries, Ltd.**
Tokyo 100-8315 (JP)

(72) Inventor: **KAWASAKI, Shuichi**
Nagoya-shi, Aichi 455-85 (JP)

(74) Representative: **Henkel, Feiler, Hänzel**
Möhlstrasse 37
81675 München (DE)

(54) **SUPPORTING MECHANISM OF MICRO GRAVITY ROTATING APPARATUS**

(57) A rotator supporting mechanism in a microgravitational rotating apparatus comprises a magnetic bearing of the rotator so as to effect a vibration control. Recess portions 10a, 10b are provided in a casing 10. Coils 1, 2 of the magnetic bearings 11, 12 and vibration sensors 3, 4 are arranged in the recess portions 10a, 10b being fitted to the casing 10 side. A rotary shaft 30 has its upper end inserted into the recess portion 10a and its lower end inserted into the recess portion 10b and connected to a motor 13. Both ends of the rotary shaft 30 are supported by a magnetic force. Arms 24 to 27, extending horizontally on X and Y axes, have their one ends fitted to the rotary shaft 30 and the other ends fitted with experimental boxes 20 to 23. Plants, animals, etc. are placed in the boxes 20 to 23 and, while they are rotated in the space, experiments are performed. While vibration occurs in the rotary shaft 30 due to weight imbalances between each of the boxes 20 to 23, the vibration is detected by the vibration sensors 3, 4 to thereby control exciting current of the coils 1, 2, so that the vibration is controlled.



EP 1 249 396 A1

Description

TECHNICAL FIELD

[0001] The present invention relates generally to a rotator supporting mechanism in a microgravitational rotating apparatus performing experiments in the space and more particularly to a rotator supporting mechanism comprising a magnetic bearing, etc. as a bearing of the rotator to thereby actively control vibration occurring in the rotator to spread therearound.

BACKGROUND ART

[0002] Fig. 20 is a schematic plan view showing a prior art example of a rotating apparatus currently used for experiments in the space. In Fig. 20, a rotating device 60, such as a motor, has four supporting members 61, 62, 63, 64 fitted thereto extending radially. Experimental boxes 70, 71, 72, 73 are fitted to respective ends of the supporting members 61 to 64 and experimental objects, such as plants, are contained in the experimental boxes 70 to 73. In the microgravitational state, such rotating apparatus is driven by the rotating device 60 to rotate in a slow speed of about 1 rotation/second and experiments of the objects in the experimental boxes 70 to 73, while rotating, are carried out.

[0003] In the mentioned rotating apparatus, the experimental boxes 70 to 73 are fitted to the ends of the supporting members 61 to 64, so that the end-portions thereof become large in the shape. Also, while the rotating apparatus itself is symmetrical around the rotating axis, the experimental objects of different kinds and different sizes are contained in the experimental boxes 70 to 73 and there are caused weight imbalances between the experimental objects so contained. Hence, by the rotation, vibration occurs in a rotary shaft as well as in the supporting members 61 to 64 and the experimental boxes 70 to 73, thereby moving the experimental objects or giving bad influences thereon.

[0004] In the prior art rotating apparatus used in the space, as described above, vibration occurs during the rotation to be transmitted to arms, like the supporting members, and the experimental boxes, that constitute a rotator, and gives bad influences on the experimental objects.

[0005] Also, the vibration spreads to the surrounding environment via the rotary shaft and gives influences on the surrounding space equipment and apparatus as well as on the control thereof. Such vibration can be solved by structural means to the extent that the vibration is a steady-state vibration that can be known beforehand. But if the vibration accompanies changes of arbitrarily occurring vibration modes, countermeasures therefor are difficult and control thereof is also limited. Thus, any of countermeasures therefor is being desired.

[0006] As mentioned above, the vibration occurring in the space is to be avoided to the extent possible and, for this purpose, studies are currently carried out so as to use an elastic bearing, such as comprising a spring, as a bearing of the rotary shaft and also so as to suppress vibration of the shaft by controlling exciting current of a coil in a magnetic bearing. However, an effective vibration control means is not definitively obtained yet.

DISCLOSURE OF THE INVENTION

[0007] It is therefore an object of the present invention to provide a rotator supporting mechanism in a microgravitational rotating apparatus that employs a magnetic bearing as a bearing of a rotary shaft for effecting an active vibration control so that arbitrary vibration occurring in the rotating apparatus in the space to spread to the surrounding environment via the rotary shaft may be actively controlled and arbitrary modes of the vibration may be suppressed.

[0008] It is also an object of the present invention to provide a rotator supporting mechanism in a microgravitational rotating apparatus that employs a magnetic coil provided around a rotary shaft of a rotator or provided in a bearing of the rotary shaft for effecting an active vibration control by changing control inputs corresponding to changes in the vibration characteristics or in the natural frequency so that arbitrary vibration occurring in the rotating apparatus in the space to spread to the surrounding environment via the rotator may be actively controlled and arbitrary modes of the vibration may be suppressed.

[0009] It is another object of the present invention to provide a rotator supporting mechanism in a microgravitational rotating apparatus in which a magnetic bearing of the microgravitational rotating apparatus is improved to comprise an active vibration control magnetic bearing and a bias control magnetic bearing separately from each other to thereby effectively control even a very small vibration so that no vibration may spread to a casing side via the magnetic bearings and no bad influence may be given on equipment or apparatus outside of the casing.

[0010] Also, it is still another object of the present invention to provide a rotator supporting mechanism in a microgravitational rotating apparatus in which a support mechanism by means of a magnetic bearing is added with an elastic support mechanism so that, even while the magnetic bearing is supplied with no electric power, a rotary shaft may be supported at a central position and, even at the time of operation start, no collision or hitting of the rotary shaft occurs.

[0011] In order to achieve the mentioned objects, the present invention provides means of the following (1) to (23).

(1) A rotator supporting mechanism in a microgravitational rotating apparatus, the rotator comprising a rotary shaft, provided within a casing of the microgravitational rotating apparatus, having its both

ends or one end supported to the side of the casing by a bearing of the rotator supporting mechanism so as to be rotationally driven by a motor, a plurality of arms, extending radially, having their one ends fitted to a circumferential periphery of the rotary shaft and a plurality of boxes, fitted to the other ends of the plurality of arms, in which a gravitational, or gravity-adding, object is placed, characterized in that the rotator supporting mechanism comprises a control unit that controls a position holding force of the bearing for holding the rotary shaft so as to effect a vibration control of the rotary shaft.

(2) A rotator supporting mechanism as mentioned in (1) above, characterized in that the bearing is a magnetic bearing, having a coil, fitted to the casing side being arranged closely to a circumferential periphery of the rotary shaft, the rotator supporting mechanism further comprises a plurality of vibration sensors fitted to the casing side being arranged closely to the coil as well as closely to the circumferential periphery of the rotary shaft and the control unit takes displacement signals sent from the plurality of vibration sensors to thereby detect vibration of the rotary shaft from displacement of the rotary shaft and controls exciting current of the coil so as to effect the vibration control.

(3) A rotator supporting mechanism as mentioned in (2) above, characterized in that the plurality of vibration sensors, instead of being fitted to the casing side, are fitted both to the casing side and the rotary shaft or only to the rotary shaft and the control unit takes the displacement signals sent from the plurality of vibration sensors and controls the exciting current of the coil so as to effect an active vibration control of the rotary shaft.

(4) A rotator supporting mechanism as mentioned in (2) or (3) above, characterized in that the rotator supporting mechanism further comprises a gap sensor or displacement sensor fitted to the casing side being arranged closely to the coil and the control unit measures a distance between the rotary shaft and the gap sensor or displacement sensor and controls the exciting current of the coil so as to effect an active vibration control of the rotary shaft.

(5) A rotator supporting mechanism as mentioned in (2) or (3) above, characterized in that the rotator supporting mechanism further comprises an optical sensor or laser displacement gauge fitted to the casing side being arranged closely to the coil and the control unit measures a distance between the rotary shaft and the optical sensor or laser displacement gauge and controls the exciting current of the coil so as to effect an active vibration control of the rotary shaft.

(6) A rotator supporting mechanism as mentioned in (4) above, characterized in that the rotator supporting mechanism, instead of comprising the plurality of vibration sensors, comprises only the gap sensor or displacement sensor fitted to the casing side being arranged closely to the coil and the control unit measures the distance between the rotary shaft and the gap sensor or displacement sensor or measures the displacement of the rotary shaft to thereby detect the vibration of the rotary shaft and controls the exciting current of the coil so as to effect the active vibration control of the rotary shaft.

(7) A rotator supporting mechanism as mentioned in any one of (2) to (4) above, characterized in that the control unit takes the displacement signals from the plurality of vibration sensors to thereby detect the vibration of the rotary shaft, compares the vibration with a predetermined vibration demand value and controls the exciting current of the coil so that the vibration may be suppressed below the vibration demand value.

(8) A rotator supporting mechanism as mentioned in any one of (4) to (6) above, characterized in that the control unit, based on signals from any one of the gap sensor, displacement sensor, optical sensor and laser displacement gauge, measures the distance to the rotary shaft or the displacement of the rotary shaft to thereby detect the vibration of the rotary shaft, compares a spectrum of the vibration with a predetermined spectrum demand value and controls the exciting current of the coil so that the vibration may be actively suppressed below the spectrum demand value.

(9) A rotator supporting mechanism as mentioned in any one of (2) to (8) above, characterized in that if and while the control unit detects acceleration or amplitude of the vibration in excess of a demand value, the control unit effects the vibration control of the rotary shaft so that the vibration may be suppressed below the demand value concentrically with respect to a vibration range in excess of the demand value.

(10) A rotator supporting mechanism as mentioned in any one of (2) to (9) above, characterized in that if and while the- control -unit detects acceleration or amplitude of the vibration in excess of a demand value, the control unit effects the vibration control of the rotary shaft so that the vibration may be suppressed below the demand value concentrically with respect to a vibration range in excess of the demand value and at the same time stores information on frequency and acceleration or amplitude or all of these data of the vibration in excess of the demand value so that the information may be reflected on a control law that enables subsequent active vibration controls.

(11) A rotator supporting mechanism as mentioned in any one of (2) to (9) above, characterized in that if and while the control unit detects acceleration or amplitude of the vibration in excess of a demand value, the control unit effects the vibration control of the rotary shaft so that the vibration may be sup-

pressed below the demand value concentrically with respect to a vibration range in excess of the demand value and at the same time compares information on frequency and acceleration or amplitude or all of these data of the vibration in excess of the demand value with previously stored vibration data so that a cause of the vibration may be grasped.

(12) A rotator supporting mechanism as mentioned in any one of (2) to (9) above, characterized in that if and while the control unit detects acceleration or amplitude of the vibration in excess of a demand value, the control unit effects the vibration control of the rotary shaft so that the vibration may be suppressed below the demand value concentrically with respect to a vibration range in excess of the demand value and at the same time compares information on frequency and acceleration or amplitude or all of these data of the vibration in excess of the demand value with previously stored vibration data so that a cause of the vibration may be grasped and learned to be reflected on a control law that is owned by the control unit to thereby enhance a control ability.

(13) A rotator supporting mechanism as mentioned in (1) above, characterized in that the bearing comprises a bearing supporting both ends of the rotary shaft and a vibration control coil arranged around the rotary shaft with a predetermined gap being maintained from the rotary shaft, the rotator supporting mechanism further comprises a plurality of vibration sensors fitted to the casing side being arranged closely to the vibration control coil as well as being equally spaced around the rotary shaft with a predetermined gap being maintained from the rotary shaft and the control unit takes displacement signals of the gap sent from the plurality of vibration sensors and, if the displacement signals are in excess of a predetermined value, controls exciting current of the vibration control coil and, in controlling the excitation of the vibration control coil, the control unit puts out signals of which amplitude is changed by combining a linear signal and a non-linear signal corresponding to sizes of the displacement signals so as to effect an active vibration control.

(14) A rotator supporting mechanism as mentioned in (13) above, characterized in that the bearing supporting both ends of the rotary shaft is a magnetic bearing and the magnetic bearing not only functions to support the rotary shaft but also functions as the vibration control coil.

(15) A rotator supporting mechanism as mentioned in (13) above, characterized in that the vibration control coil comprises coil portions divided corresponding to number and position of the plurality of vibration sensors and the control unit judges a position of the vibration sensor of which displacement signal is the largest out of the displacement signals sent from the plurality of vibration sensors and controls exciting current of that coil portion of the vibration control coil corresponding to the position of the vibration sensor.

(16) A rotator supporting mechanism as mentioned in (14) above, characterized in that the magnetic bearing comprises coil portions divided corresponding to number and position of the plurality of vibration sensors and the control unit judges a position of the vibration sensor of which displacement signal is the largest out of the displacement signals sent from the plurality of vibration sensors and controls exciting current of that coil portion of the magnetic bearing corresponding to the position of the vibration sensor.

(17) A rotator supporting mechanism as mentioned in (15) or (16) above, characterized in that the control unit measures time-wise changes of the displacement signals sent from the plurality of vibration sensors, computes a change rate and an inclination of the changes of the respective time-wise changes and, based on any of the computation results, enables to adjust exciting force of the magnetic bearing so as to effect an appropriate vibration control.

(18) A rotator supporting mechanism as mentioned in (2) above, characterized in that the magnetic bearing supporting both ends of the rotary shaft comprises a vibration control magnetic bearing and a bias control magnetic bearing that effects a position holding of the rotary shaft.

(19) A rotator supporting mechanism as mentioned in (2) above, characterized in that the magnetic bearing supporting both ends of the rotary shaft comprises two vibration control magnetic bearings and a bias control magnetic bearing arranged between the two vibration control magnetic bearings.

(20) A rotator supporting mechanism as mentioned in (2) above, characterized in that the magnetic bearing supporting both ends of the rotary shaft comprises two bias control magnetic bearings that effect a position holding of the rotary shaft and a vibration control magnetic bearing arranged between the two bias control magnetic bearings.

(21) A rotator supporting mechanism as mentioned in any one of (18) to (20) above, characterized in that the vibration control magnetic bearing functions only to effect the vibration control of the rotary shaft and the bias control magnetic bearing functions to effect the position holding of the rotary shaft as well as to effect a position control of the rotary shaft so as to weaken the position holding force of the rotary shaft while the vibration control magnetic bearing is effecting the vibration control.

(22) A rotator supporting mechanism as mentioned in (2) above, characterized in that the magnetic bearing supporting both ends of the rotary shaft is supported to the casing side via an elastic support mechanism that is arranged on an outer circumfer-

ential side of the magnetic bearing and a shaft supporting force of the elastic support mechanism is set to a value smaller than a shaft supporting force of the magnetic bearing.

(23) A rotator supporting mechanism as mentioned in (22) above, characterized in that the elastic support mechanism comprises a main body holding the magnetic bearing for supporting the rotary shaft and a plurality of springs connecting an outer circumferential surface of the main body and the casing side.

(24) A rotator supporting mechanism as mentioned in (22) above, characterized in that the elastic support mechanism comprises a main body holding the magnetic bearing for supporting the rotary shaft and an elastic member, made of an elastic material, connecting an outer circumferential surface of the main body and the casing side.

[0012] In the means (1) above, objects as experimental objects that add gravity in the microgravitational environment in the space are placed in the plurality of boxes and the boxes rotate around the rotary shaft. The objects are plants or animals, for example, and there are. caused imbalances in the weight between each of the boxes. Hence, when the rotator rotates, vibration occurs due to differences in the acceleration. The control unit controls the position holding force of the bearing for holding the rotary shaft to thereby suppress displacements of the rotary shaft caused by the vibration. Thus, the vibration of the rotator, that comprises the rotary shaft, the arms and the boxes, can be controlled to be suppressed to the minimum.

[0013] In the means (2) above, the rotary shaft has its both ends or one end supported by the magnetic bearing. If vibration occurs in the rotary shaft due to imbalances in the objects in the boxes or imbalances in the system, the vibration is detected as displacements of the rotary shaft by the vibration sensors arranged closely to the circumferential periphery of the rotary shaft and signals thereof are inputted into the control unit. The control unit detects the vibration of the rotary shaft based on these displacement signals and controls the exciting current of the coil of the magnetic bearing so as to effect the vibration control of the rotary shaft. Thus, the vibration is controlled to be suppressed and is prevented from spreading to the surrounding environment in the space via the bearing of the rotary shaft.

[0014] In the means (3) above, the vibration sensors are fitted both to the casing side and the rotary shaft or fitted to the rotary shaft. In the means (4) above, in addition to the vibration sensors, the gap sensor or displacement sensor is provided and in the means (5) above, the optical sensor or laser displacement gauge is provided. Thus, the detection of the vibration of the rotary shaft can be done with a higher accuracy.

[0015] In the means (6) above, instead of the vibration sensors of the means (4) above, the construction is made so as to detect the vibration only by the gap sensor or displacement sensor. Hence, the construction of the sensors can be simplified according to the sensing purpose or the objects in the boxes.

[0016] In the means (7) above, if the control unit detects the vibration of the rotary shaft, it compares the vibration with the previously set vibration demand value to which the vibration as in a rotating device is to be suppressed and controls the exciting current of the coil so that the vibration may be suppressed below the demand value. Hence, bad influences given on other equipment or apparatus in the space can be avoided.

[0017] In the means (8) above, the control unit detects the vibration based on the displacements of the rotary shaft detected by the gap sensor, the displacement sensor, the optical sensor or the laser displacement gauge, compares the vibration with the spectrum demand value that is set with respect to the vibration spectrum and effects the control so as to suppress the vibration below the demand value. In the means (9) above, if the detected vibration acceleration or amplitude is in excess of the demand value, the control unit effects the vibration control so that the vibration may be suppressed below the demand value concentrically with respect to the vibration range in excess of the demand value. Thus, the vibration can be instantaneously suppressed.

[0018] In the means of (10) above, the control unit stores the information of the frequency, acceleration, amplitude, etc. of the detected vibration to be reflected on the control law of the subsequent vibration controls. In the means (11) above, the detected vibration data are compared with the previously stored data so that the cause of the vibration may be grasped and, in the means (12) above, the cause of the vibration is grasped based on the result of the comparison and learned so as to be reflected on the control law. Hence, by the learning function, the vibration control becomes more accurate.

[0019] In the means (13) above, the vibration of the rotator is detected as the displacements of the gap between the rotary shaft and the casing side by the plurality of vibration sensors arranged around the rotary shaft and the displacement signals sent from the vibration sensors are inputted into the control unit. If the displacement signals are large as compared with the predetermined value that is set to the ordinary non-vibrating state, the control unit controls the exciting current of the vibration control coil to thereby control the displacements of the gap caused by the vibration of the rotator. In this control of the vibration control coil, the control unit puts out the signals of which amplitude is changed by combining the linear signal and the non-linear signal corresponding to the sizes of the displacement signals sent from the vibration sensors and the vibration control coil is controlled by the output signals so put out by the control unit. By this control, the vibration can be optimally suppressed and converged.

[0020] In the means (14) above, the bearing supporting both ends of the rotary shaft is a magnetic bearing and this magnetic bearing functions both as the rotary

shaft supporting bearing and the vibration control coil. Hence, the structure of the vibration control system of the rotator is simplified and the vibration can be optimally suppressed and converged at both ends of the rotary shaft.

[0021] In the means (15) above, the vibration control coil is divided into the coil portions and also in the means (16) above, the coil of the magnetic bearing is divided into the coil portions. Thereby, the exciting current of the coil portion corresponding to the position where the displacement due to the vibration of the rotator is the largest is effectively controlled and thus the vibration of the rotator can be more effectively controlled.

[0022] In the means (17) above, the control unit computes the change rate and the inclination of the changes with respect to the time-wise changes in the vibration signals sent from the vibration sensors and corresponding to the sizes of the change rate and the inclination, the excitation of the vibration control coil is controlled. Hence, a higher accuracy of the vibration control can be realized.

[0023] In the means (18) above, the magnetic bearing supporting both ends of the rotary shaft is constructed by the vibration control magnetic bearing that effects the active vibration control and the bias control magnetic bearing that effects the position holding. The bias control magnetic bearing holds the rotary shaft at the central position of the rotation by the magnetic force. The vibration control magnetic bearing is controlled such that, upon occurrence of the vibration of the rotary shaft, the vibration control magnetic bearing generates a magnetic force so as to weaken the position holding force of the bias control magnetic bearing to a predetermined extent to thereby mitigate the position holding force of the rotary shaft. At the same time, the control to effect the active vibration control of the rotary shaft is carried out. Thus, the vibration caused by the stiff supporting force given by the bias control magnetic bearing is mitigated and even a very small vibration is prevented from spreading outside. Hence, the vibration can be effectively controlled.

[0024] In the means (19) above, the magnetic bearing supporting both ends of the rotary shaft is constructed by the two vibration control magnetic bearings and the bias control magnetic bearing arranged between them. Hence, like in the means (18) above, the vibration occurring in the rotary shaft can be prevented from spreading outside of the casing. Moreover, the rotary shaft has its both ends supported by the magnetic bearing having therein the two vibration control magnetic bearings that are arranged in a good balance and thus a more effective vibration control becomes possible.

[0025] In the means (20) above, the magnetic bearing supporting both ends of the rotary shaft is constructed by the two bias control magnetic bearings and the vibration control magnetic bearing arranged between them. Hence, like in the means (18) above, the vibration occurring in the rotary shaft can be prevented from spreading outside of the casing. Moreover, the rotary shaft has its both ends supported by the magnetic bearing having therein the two bias control magnetic bearings that are arranged in a good balance and thus the position holding of the rotary shaft is ensured and a more effective vibration control becomes possible.

[0026] In the means (21) above, while the vibration control magnetic bearing is effecting the vibration control of the rotary shaft, the exciting current of the bias control magnetic bearing is controlled so as to weaken the position holding force of the rotary shaft to a predetermined extent. Thereby, the position holding force given by the bias control magnetic bearing for holding the rotary shaft is weakened and the vibration of the rotary shaft is given an increased freedom relative to the bias control magnetic bearing. Thus, the vibration is prevented from spreading to the casing side via the bias control magnetic bearing and is effectively controlled by the vibration control magnetic bearing.

[0027] In the means (22) above, the magnetic bearing, while supporting both ends of the rotary shaft, is supported by the elastic support mechanism and thereby the rotary shaft can be supported at the central position of the rotation, even while the magnetic bearing is being supplied with no power. Also, the shaft supporting force of the elastic support mechanism is set smaller than that of the magnetic bearing. On the other hand, the shaft supporting force of the elastic support mechanism is set so as to have a minimum shaft supporting force to support the rotary shaft at the central position while the magnetic bearing is being supplied with no power and no supporting force of the magnetic bearing is being generated. Hence, the vibration occurring in the rotary shaft is prevented from spreading to the casing side via the magnetic bearing and the vibration is effectively controlled by the magnetic bearing.

[0028] In the means (23) above, the elastic support mechanism is constructed by the main body holding the magnetic bearing and the plurality of springs connecting the main body to the casing side. Also, in the means (24) above, the elastic support mechanism is constructed by the main body holding the magnetic bearing and the elastic member, made of an elastic material, connecting the main body to the casing side. Thus, the rotary shaft can be elastically supported by a simple elastic support mechanism. The elastic support may be realized not only by such an elastic material as rubber, sponge rubber or urethane but also by a supporting means using a fluid material, a fluid bearing, etc.

BRIEF DESCRIPTION OF THE DRAWINGS

[0029] Figs. 1(a) to (c) show a rotator supporting mechanism in a microgravitational rotating apparatus of a first embodiment according to the present invention, wherein Fig. 1(a) is a cross sectional side view, Fig. 1 (b) is a cross sectional view seen from arrows on line A-A of Fig. 1(a) and Fig. 1(c) is a cross sectional view

seen from arrows on line B-B of Fig. 1(a).

[0030] Fig. 2 is a control system diagram of the rotator supporting mechanism of the first embodiment.

[0031] Fig. 3 is a control flow chart of the rotator supporting mechanism of the first embodiment.

[0032] Fig. 4 is a cross sectional side view of an upper half portion of a rotator supporting mechanism in a microgravitational rotating apparatus of a second embodiment according to the present invention.

[0033] Figs. 5(a) and (b) are graphs showing two examples of a demand value and a control effect of a vibration control in the rotator supporting mechanisms of the first and the second embodiments.

[0034] Figs. 6(a) to (c) show an active control system as a rotator supporting mechanism in a microgravitational rotating apparatus of a third embodiment according to the present invention, wherein Fig. 6(a) is a cross sectional side view, Fig. 6(b) is a cross sectional view seen from arrows on line C-C of Fig. 6(a) and Fig. 6(c) is a cross sectional view seen from arrows on line D-D of Fig. 6(a).

[0035] Fig. 7 is a control system diagram of the third embodiment.

[0036] Figs. 8(a) to (c) show three patterns of excitation of a vibration control coil of the third embodiment, wherein Figs. 8(a) and (b) show patterns combining linear and non-linear ones and Fig. 8(c) shows a pattern having only a non-linear one.

[0037] Fig. 9 is a control system diagram of a rotator supporting mechanism in a microgravitational rotating apparatus of a fourth embodiment according to the present invention.

[0038] Fig. 10 is a cross sectional side view of a rotator supporting mechanism in a microgravitational rotating apparatus of a fifth embodiment according to the present invention.

[0039] Figs. 11(a) and (b) show cross sectional portions of the rotator supporting mechanism of the fifth embodiment shown in Fig. 10, wherein Figs. 11(a) is a cross sectional view seen from arrows on line E-E of Fig. 10 and Fig. 11(b) is a cross sectional view seen from arrows on line F-F of Fig. 10.

[0040] Figs. 12(a) and (b) are signal timing charts showing a vibration control state with respect to the fifth embodiment, wherein Fig. 12(a) shows an example in which a bias control magnetic bearing is not controlled and Fig. 12(b) shows an example in which the bias control magnetic bearing is controlled.

[0041] Fig. 13 is a cross sectional side view of a rotator supporting mechanism in a microgravitational rotating apparatus of a sixth embodiment according to the present invention.

[0042] Fig. 14 is a cross sectional side view of a rotator supporting mechanism in a microgravitational rotating apparatus of a seventh embodiment according to the present invention.

[0043] Fig. 15 is a cross sectional side view of a rotator supporting mechanism in a microgravitational rotating apparatus of an eighth embodiment according to the present invention.

[0044] Fig. 16 is a cross sectional view seen from arrows on line G-G of Fig. 15.

[0045] Fig. 17 is a cross sectional view seen from arrows on line H-H of Fig. 15.

[0046] Figs. 18(a) and (b) show a rotator supporting mechanism in a microgravitational rotating apparatus of a ninth embodiment according to the present invention, wherein Fig. 18(a) is a cross sectional view taken on a substantially same line as the line G-G of Fig. 15 and Fig. 18(b) is a cross sectional view taken on line J-J of Fig. 18(a).

[0047] Fig. 19 is a cross sectional view of the ninth embodiment taken on a substantially same line as the line H-H of Fig. 15.

[0048] Fig. 20 is a schematic plan view showing a prior art example of a rotating apparatus currently used for experiments in the space.

BEST MODE FOR CARRYING OUT THE INVENTION

[0049] Herebelow, the invention will be described more concretely based on embodiments with reference to appended drawings.

[0050] Figs. 1(a) to (c) show a rotator supporting mechanism in a microgravitational rotating apparatus of a first embodiment according to the present invention, wherein Fig. 1(a) is a cross sectional side view, Fig. 1 (b) is a cross sectional view seen from arrows on line A-A of Fig. 1(a) and Fig. 1(c) is a cross sectional view seen from arrows on line B-B of Fig. 1(a). In Fig. 1(a), numeral 10 designates a casing, that contains therein an entire rotator. Within the casing 10, there are provided recess portions 10a, 10b projecting outwardly from upper and lower outer walls of the casing 10 and magnetic bearings 11, 12 are arranged on inner circumferential wall surfaces of the recess portions 10a, 10b, respectively. The magnetic bearings 11, 12 comprise coils 1, 2 for excitation that are arranged on the inner circumferential wall surfaces of the recess portions 10a, 10b, respectively, so as to form the magnetic bearings. Numerals 3, 4 designate vibration sensors, that are arranged on casing inner sides of the coils 1, 2 in the recess portions 10a, 10b, respectively, for detecting displacements of gaps between the sensors 3, 4 and a rotary shaft 30 to thereby detect vibration of the rotary shaft 30, as will be described later. The vibration sensors 3, 4 are arranged, as shown in Fig. 1(c), in four pieces symmetrically around the rotary shaft 30 so that vibration displacements of the rotary shaft 30 may be detected in the directions of $\pm X$ and $\pm Y$ axes. Also, as will be described later, the vibration sensors may be arranged so that displacements of the rotary shaft 30 in the direction of $\pm$ Z axis, that is, in the axial direction of the rotary shaft, may be detected. It is to be noted that the vibration sensors 3, 4 may be fitted not only to the casing 10 side but also to the rotary shaft 30 side or they may be fitted

only to the rotary shaft 30 side.

[0051] Numeral 30 designates the rotary shaft, as mentioned above, that has its upper and lower ends arranged in the recess portions 10a, 10b, respectively, such that the upper end is supported by the magnetic bearing 11 and the lower end is supported by the magnetic bearing 12 and is connected to a motor 13. Thus, the rotary shaft 30 is supported in a space by the magnetic force with a predetermined gap being maintained between the rotary shaft 30 and the coils 1, 2 to be rotatable by the motor 13. As shown in Fig. 1(b), four arms 24, 25, 26, 27 have their one ends fixed to an outer circumferential periphery of the rotary shaft 30 extending horizontally in the directions of X and Y axes and have the other ends fitted with experimental boxes or containers (hereinafter simply referred to as "the experimental boxes") 20, 21, 22, 23.

[0052] It is to be noted that the rotary shaft 30 may be constructed by a permanent magnet or an exciting coil so as to be supported by a magnetic repulsive force or attractive force and also the magnetic bearing may be provided not on both ends of the rotary shaft 30 but only on either one thereof.

[0053] In the rotator comprising the rotary shaft 30, the arms 24 to 27 and the experimental boxes 20 to 23, mentioned above, experimental objects of plants, animals, etc. are placed in the experimental boxes 20 to 23. In the space environment, the motor 13 is driven to rotate the experimental boxes 20 to 23 in a slow speed so that experiments to observe a growing state of the plants, a living state of the animals, etc. in the space may be carried out. As various experimental objects having different shapes, sizes and weights are so contained in the experimental boxes 20 to 23, when they are rotated, there occur differences in the acceleration caused by the imbalances in the weight between each of the experimental boxes 20 to 23 and vibration occurs in the experimental boxes. This vibration is conveyed to the rotary shaft 30 via the arms 24 to 27 and further to the casing 10 via the bearing portions, thereby giving bad influences not only on the experiments but also on the surrounding environment.

[0054] Thus, in the present first embodiment, the construction is made such that the magnetic bearings 11, 12 are employed as the bearings of the rotary shaft 30 and thereby the rotary shaft 30 is supported to the casing 10 side by the magnetic force so as to make no contact with a supporting portion of the casing 10. If vibration occurs in the rotary shaft 30, the vibration is detected by the respective four vibration sensors 3, 4 arranged on the X and Y axes around the both end portions of the rotary shaft 30. The vibration sensors 3, 4 detect variations caused by the vibration in the gaps between the rotary shaft 30 and the sensors and input signals thereof into a control unit (not shown). If vibration occurs to cause variations in the gaps, the control unit controls the currents of the coils 1, 2 existing at the positions corresponding to the variations so that the gaps may return to the original gaps and thereby an active vibration control may be effected.

[0055] While illustration is omitted, the coils 1, 2 may be constructed, for example, such that in each of the coils, four mutually independent windings are arranged so that the magnetic force may act in the four directions of X and Y axes and the control unit controls excitation of the coil existing at the position where the variation in the gap between the coil and the rotary shaft 30 caused by inclining of the rotary shaft 30 is the largest to thereby adjust the repulsive force or attractive force relative to the rotary shaft 30 for the vibration control.

[0056] Fig. 2 is a control system diagram of the rotator supporting mechanism of the first embodiment according to the present invention. The vibration sensors 3, 4 arranged at the upper and lower end portions of the rotary shaft 30 comprise vibration sensors 3a, 3b, 3c, 3d and 4a, 4b, 4c, 4d, respectively, and each of their detected signals is inputted into a control unit 14. The control unit 14 controls to drive the motor 13 and, at the same time, monitors the vibrational displacements of the ends of the rotary shaft 30 in the four directions of X and Y axes of the vibration sensors 3, 4. If the gaps between the sensors and the rotary shaft 30 become smaller or larger, the control unit 14 controls the exciting current of the windings of the coils 1, 2 existing at the corresponding position on the X and Y axes so as to strengthen the repulsive force or attractive force between the rotary shaft and the coils to thereby return the gaps to the original state.

[0057] Numeral 15 designates a storage unit, that previously stores data on demand value patterns of vibration frequency spectrum, amplitude or acceleration. In monitoring the vibration of the rotary shaft 30 by the signals from the vibration sensors 3, 4, the control unit 14 compares the vibration with the demand value. When the vibration becomes larger to cause displacements of the rotary shaft and further becomes in excess of the demand value, the control unit 14 controls the exciting currents of the coils so as to reduce the vibration and further continues the control so that the vibration of the rotary shaft 30 becomes below the demand value.

[0058] Also, if the control is done such that the control unit compares the vibration with the demand value to thereby grasp and learn the vibration characteristics and reflects them on its own control laws, then the control ability can be further enhanced.

[0059] Fig. 3 is a control flow chart of the rotator supporting mechanism of the first embodiment. In Fig. 3, steps of the control are shown by S1 to S5. When the rotator starts to rotate, the control unit 14 first takes signals detected by each of the vibration sensors 3, 4(S1) and then takes data of the demand value from the storage unit 15 for comparison with the detected values of the vibration and monitors the vibration of the rotary shaft 30 (S2). Then, the control unit 14 ascertains whether the vibration detected by each of the sensors exceeds the demand value or not (S3) and if the vibra-

tion is smaller than the demand value, the step returns to S1 for further monitoring the signals detected by each of the vibration sensors. If the vibration is in excess of the demand value, the control unit 14 controls the currents of the windings of the coils existing at the position of the vibration sensors causing the vibration in excess of the demand value to thereby adjust the electromagnetic force so that the gaps between the rotary shaft, having the vibrational displacements, and the coils may return to the original state and the vibration may be reduced (S4). Then, at the step S5, if the rotation is to continue, the step returns to S1 for a continued control and if the rotation is to finish, the control finishes.

[0060] Fig. 4 is a cross sectional side view of a rotator supporting mechanism in a microgravitational rotating apparatus of a second embodiment according to the present invention, wherein only an upper half portion of the rotating apparatus is shown and illustration of a lower portion thereof is omitted. In Fig. 4, there are provided recess portions 10a, 10b (illustration of 10b is omitted) on upper and lower outer walls of a casing 10. A rotary shaft 30 has its both ends inserted into the recess portions 10a, 10b, respectively, to be supported by magnetic bearings, like in the case of Fig. 1. A vibration sensor 5 is fitted to an inner surface of a bottom (or ceiling) wall of the recess portion 10a so as to oppose an upper end face of the rotary shaft 30. Also, an annular fin-like fixing plate 30a is fitted to the rotary shaft 30 at a mid position of the upper end portion of the rotary shaft 30. Coils 7 are fitted to the casing 10 side so as to hold the fixing plate 30a therebetween with a predetermined gap being maintained between the fixing plate 30a and the coils 7. Construction of other portions is the same as that of the first embodiment shown in Fig. 1 and description thereon is omitted.

[0061] It is to be noted that the abovementioned fixing plate 30a may be constructed by a permanent magnet or an exciting coil to generate a magnetic repulsive force or attractive force to thereby strengthen the repulsive force or attractive force relative to the coils 7.

[0062] In the construction as mentioned above, displacements of the rotary shaft 30 caused by the vibration in the directions of ±X and ±Y axes are detected by the vibration sensors 3, 4 to be inputted into the control unit. Then, like in the first embodiment shown in Figs. 1 and 2, excitation of the coils 1, 2 is controlled so as to solve the displacements and this is reflected on the vibration of the rotary shaft in the direction of ±X and ±Y axes so that the vibration may be reduced.

[0063] In the present second embodiment, in addition to the above construction, displacements of the rotary shaft 30 in the axial direction, or in the direction of ±Z axis, are detected by the vibration sensor 5 to be inputted into the control unit and excitation of the coils 7 is controlled so as to solve the displacements in the direction of ±Z axis for reducing the vibration. Thus, the displacements caused by the vibration in the directions of ±X, ±Y and ±Z axes are detected by the vibration sensors 3, 4 and 5 and the vibrations in the three dimensional directions can be accurately controlled. It is to be noted that the control system of the second embodiment is basically the same as that described with respect to Fig. 2 and description and illustration thereof are omitted.

[0064] Figs. 5(a) and (b) are graphs showing two examples of the demand value and the control effect of the vibration control in the rotator supporting mechanisms of the first and the second embodiments as described above. Fig. 5(a) shows an example where the vibration is of the rotary shaft 30 having a natural vibration of a single natural value (X). In this example, a rotator supporting mechanism having magnetic bearings of the present invention is used for the demand value (Y) and thereby the vibration is controlled to become patterns of the vibration (XA) that are below the demand value (Y).

[0065] Fig. 5(b) shows an example where patterns of the natural frequency change to those (X_2) from those (X_1). This is such a case, for example, where the plants in the experimental boxes grow to thereby change the vibration characteristics of the experimental boxes. In this case also, likewise by applying the rotator supporting mechanism of the present invention, the natural vibration (X_1) is controlled to become patterns of the vibration (XA) that are below the demand value (Y) and the natural vibration (X_2) is controlled to become patterns of the vibration (XB) that are also below the demand value (Y).

[0066] In the first and the second embodiments as described above, while the magnetic bearings are employed to control the exciting current of the coils for controlling the vibration, such a vibration control is done by vibration control inputs of a linear type or a simple nonlinear type. Hence, an effective vibration control cannot necessarily be achieved and there is a limitation in controlling the changes in the vibration modes that arise arbitrarily. Therefore, a further improvement in this regard is being desired. Thus, a third embodiment according to the present invention will be described next.

[0067] Figs. 6(a) to (c) show an active control system as a rotator supporting mechanism in a microgravitational rotating apparatus of a third embodiment according to the present invention, wherein Fig. 6(a) is a cross sectional side view, Fig. 6(b) is a cross sectional view seen from arrows on line C-C of Fig. 6(a) and Fig. 6(c) is a cross sectional view seen from arrows on line D-D of Fig. 6(a). In Fig. 6(a), a rotary shaft 50 is supported to a structural part 60 via a bearing 52 so as to be rotatable in the microgravitational space. It is to be noted that while the rotary shaft 50 is shown only by illustration of a lower end portion thereof, an upper end portion thereof is also supported likewise by the bearing. A coil 1 for the vibration control purpose surrounds the rotary shaft 50 with a predetermined gap being maintained between the coil 1 and the rotary shaft 50 and is supported and fitted to a supporting member 51. Also, a vibration sensor 3 is arranged slightly above the coil 1 with a predeter-

mined gap being maintained between the vibration sensor 3 and the rotary shaft 50 and is likewise supported and fitted to the supporting member 51.

[0068] In Fig. 6(b), the coil 1, surrounding the rotary shaft 50 with the predetermined gap therebetween, is constructed by four coils, as will be described below, so that displacements of the rotary shaft 50 caused by the vibration may be solved by the magnetic force. Also, in Fig. 6(c), the vibration sensor 3, arranged slightly above the coil 1, comprises four vibration sensors 3a, 3b, 3c, 3d, that are arranged in the directions of ±X and ±Y axes, being equally spaced between each of them, around the rotary shaft 50 with the predetermined gaps being maintained between the respective vibration sensors and the rotary shaft. If the rotary shaft 50 displaces by the vibration, changes in the gaps between the rotary shaft 50 and the vibration sensors 3a to 3d are detected by the vibration sensors 3a to 3d and also the vibration directions are detected from the positional changes of the rotary shaft 50 at the four positions of the vibration sensors 3a to 3d.

[0069] Fig. 7 is a control system diagram of the third embodiment shown in Fig. 6. As shown there, signals of the vibration of the rotary shaft 50 detected by the four vibration sensors 3a to 3d surrounding the rotary shaft 50 are taken into a control part 43 of a control unit 40. The control part 43 compares the detected values of the gaps between the rotary shaft 50 and the vibration sensors 3a to 3d with a reference value of the gap that is set as a value when no vibration occurs and decides the sensor of the four vibration sensors 3a to 3d that detects the smallest or largest variation in the detected signals. That is, if the sensor detecting the smallest gap between the rotary shaft 50 and the vibration sensor is employed, the coil existing at the same position as that sensor is fed with exciting current so as to strengthen a repulsive force relative to the rotary shaft 50 to thereby suppress displacements of the rotary shaft 50. Or, reversely, if the sensor detecting the largest gap is employed, the coil of the same position of that sensor is excited so as to strengthen an attractive force of the coil and thereby the rotary shaft 50 returns to the right position to reduce the vibration.

[0070] Also, in comparing the detected signals with the reference value, the control unit 40 obtains a timewise change rate and an inclination of the change of the signals detected by the sensors and, based on the result thereof, the vibration can be detected.

[0071] In Fig. 7, when the control part 43 decides the coil to be excited, it then judges the size of the difference between the displaced gap and the reference gap and, according to the size of the displacement, changes the amplitude of the input current of the coil by combining outputs of a linear vibration control part 41 and a non-linear vibration control part 42 to thereby control the exciting current of any of coils (A), (B), (C) and (D) of the coil 1. For example, as will be described below with respect to Fig. 8, the input signals of the coil are first controlled linearly and when the vibration exceeds a predetermined reference value, the input signals of the coil are controlled non-linearly with a curved line.

[0072] Figs. 8(a) to (c) show three patterns of excitation current of the coil controlled by the control unit 40 for the vibration control in the present third embodiment. In the pattern of Fig. 8(a), up to amplitude A_1 of the input current to be inputted into the coil or up to input signal S_1 of the coil, linear input signals are put out from the linear vibration control part 41. From the amplitude A_1 or from the input signal S_1, non-linear input signals on a curved line are put out from the non-linear vibration control part 42. These non-linear input signals are of non-linear wave shapes that are defined, for example, by an equation: Input Signal $S = ax+ax^2+ax^3+\cdots+ax^n$ (a and n being constants, X being amplitude). This example of Fig. 8(a) is effective for a case where the amplitude of the vibration is comparatively large, the displacement of the rotary shaft 50 relative to the sensor is larger than a predetermined value and the vibration is of a low frequency, 'that is, this example is applicable to a case where the vibration is to be rapidly reduced by the non-linear part.

[0073] The example of Fig. 8(b) is a case where the amplitude of the input signals is smaller than that of the case of Fig. 8(a) ($A_1>A_2$). Up to the amplitude A_2, input signals are put out into the coil from the linear vibration control part 41. From the amplitude A_2 or from input signal S_2, input signals are put out into the coil from the non-linear vibration control part 42. This example of Fig. 8(b) is applicable to a case where the amplitude of the vibration is smaller than in the case of Fig. 8(a).

[0074] In the example of Fig. 8(c), only the output of the non-linear vibration control part 42 is applicable. This case is effective for a case where the input signals of the coil are rapidly raised so that the vibration may be rapidly controlled. In this example, effective input signals can be obtained for the vibration of a comparatively high frequency.

[0075] In the present third embodiment, the control unit 40 takes the vibrational displacement signals of the rotary shaft 50 from the vibration sensor 3, so that the control part 43 compares the size of the displacement signals from the vibration sensors with the reference value and, according to the size, changes the amplitude of the input current of the coil by combining outputs of the linear vibration control part 41 and the non-linear vibration control part 42 and then puts out input signals of the coil. Thereby, an effective vibration control can be performed. Hence, by the vibration control of the rotary shaft 50 in the microgravitational environment in the space, bad influences given on the surroundings can be prevented.

[0076] Also, as an alternative procedure, the control unit 40 takes signals from the vibration sensor 3 to thereby obtain a change rate of the vibration in a predetermined time and further to compute the size of inclination of the changes. Based on the computed values of the

quantity or based on one of the computed values, the size is decided and, based on the size so decided, the exciting current can be controlled. For example, if the change rate or the inclination of the changes is large in comparison with the predetermined value, it can be decided that the vibration is large. Or, reversely, if the change rate or the inclination of the changes is small, it can be decided that the vibration is comparatively mild.

[0077] Fig. 9 is a control system diagram of a rotator supporting mechanism in a microgravitational rotating apparatus of a fourth embodiment according to the present invention. This fourth embodiment is constructed such that the rotator supporting mechanism of the first embodiment shown in Fig. 1 is applied with the active vibration control system shown in Fig. 7.

[0078] In the present fourth embodiment, like in the construction shown in Fig. 1, the bearings of the rotary shaft 30 are constructed as the magnetic bearings 11, 12 and thereby the rotary shaft 30 is supported to the casing 10 side by the magnetic force, generated by electric current supplied from an electric source (not shown), so as to make no contact with a supporting portion of the casing 10. If vibration occurs in the rotary shaft 30, the vibration is detected by the four vibration sensors 3, 4, respectively, arranged on the X and Y axes around the both end portions of the rotary shaft 30. Variations caused by the vibration in the gaps between the rotary shaft 30 and the sensors are detected by the vibration sensors 3, 4 to be inputted into the control unit. If the gaps become smaller or larger, the control unit controls the electric currents of the coils 1, 2, arranged in the magnetic bearings 11, 12, existing at the corresponding positions of the gaps so that the gaps may return to the original gaps. Thereby, the vibration is actively controlled.

[0079] Like in the first embodiment shown in Fig. 1, the coils 1, 2 may be constructed such that in each of the coils 1, 2, four mutually independent windings are arranged so that the magnetic force may act in the four directions of X and Y axes and the control unit controls excitation of the coil existing at the position where the variation in the gap between the coil and the rotary shaft 30 caused by inclining of the rotary shaft 30 is the largest to thereby adjust the repulsive force or attractive force relative to the rotary shaft 30 for the vibration control.

[0080] In Fig. 9, the vibration sensors 3, 4 arranged at the upper and lower end portions of the rotary shaft 30 comprise vibration sensors 3a, 3b, 3c, 3d and 4a, 4b, 4c, 4d, respectively, and each of their detected signals is inputted into a control part 43 of a control unit 40. The control part 43 monitors the vibrational displacements of the ends of the rotary shaft 30 in the four directions of X and Y axes of the vibration sensors 3, 4. If the gaps between the sensors and the rotary shaft 30 become smaller or larger, the control part 43 controls the exciting current of the windings of the coils 1, 2 existing at the corresponding position on the X and Y axes so as to strengthen the repulsive force or attractive force between the rotary shaft 30 and the coils to thereby return the gaps to the original state. It is to be noted that the exciting current of the coils 1, 2 acting as a bearing is supplied from an electric source, that is not shown, and the control unit 40 is fed with electric current for the control purpose in addition to this exciting current.

[0081] When the control part 43 controls the coils 1,2, it judges the size of the difference between the displaced gap and the reference gap and, according to the size of the displacement, changes the amplitude of the input current of the coils by combining outputs of the linear vibration control part 41 and the non-linear vibration control part 42 to thereby control the exciting current of any of coils (A), (B), (C) and (D) of the coils 1, 2, as described with respect to Figs. 7 and 8. The patterns of the exciting current are the same as those shown in Fig. 8 and description thereon is omitted.

[0082] In the present fourth embodiment also, like in the third embodiment, the control part 43 compares the size of the displacement signals taken from the vibration sensors with the reference value and, according to the size, changes the amplitude of the input current by combining outputs of the linear vibration control part 41 and the non-linear vibration control part 42 and then puts out input signals of the coils 1, 2. Thereby, the exciting current of the coils 1, 2 is controlled so as to perform an effective vibration control of the rotating experimental apparatus. Thus, the vibration of the rotary shaft 30 is reduced in the microgravitational environment in the space and bad influences given on the surroundings can be prevented.

[0083] In performing the vibration control by the magnetic bearings in the microgravitational rotating apparatus, as mentioned above, the magnetic bearings perform both a bias control for supporting the rotary shaft and the active vibration control at the same time. In this case, if a very small vibration is to be actively controlled, the magnetic bearing is necessarily supplied with a very small electric current and this may often result in the impossibility of the active vibration control itself or, according to the control of the exciting current for the active vibration control, loss of the bias control ability might occur. In the bias control by the magnetic bearings, the rotary shaft is arranged centrally of the bearings and a comparatively strong power is supplied for adjusting the magnetic force and for ensuring balances of the rotary shaft. For this reason, a supporting force to be elastically generated by the magnetic force becomes a stiff supporting force and even if the vibration occurring in the rotary shaft is very small, it easily spreads to the casing side via the magnetic bearings. Hence, improvement on this point is being desired. Thus, a fifth embodiment according to the present invention for realizing the improvement will be described next.

[0084] Fig. 10 is a cross sectional side view of a rotator supporting mechanism in a microgravitational rotating apparatus of a fifth embodiment according to the present invention. In Fig. 10, like in the first embodiment

shown in Fig. 1, there are provided recess portions 10a, 10b within a casing 10. A cylindrical upper fixing member 31 and a cylindrical lower fixing member 32 are fixedly fitted in the recess portions 10a, 10b, respectively.

[0085] Like in the example of Fig. 1, a magnetic bearing 11 and a vibration sensor 3 are arranged in the upper fixing member 31. Further, a bias control magnetic bearing 35a and a thrust magnetic bearing 33 are arranged in the upper fixing member 31. In the lower fixing member 32 also, a vibration sensor 4, a bias control magnetic bearing 35b and a magnetic bearing 12 are arranged. Thus, an upper end portion of a rotary shaft 30 is supported by the magnetic bearings 11, 35a, 33 and a lower end portion thereof by the magnetic bearings 12, 35b both making no contact with the casing 10 side by the action of the magnetic force. The rotary shaft 30 is rotatably driven by a motor 34 fixed to the lower fixing member 32.

[0086] Like in Fig. 1, four arms 24, 25, 26, 27 have their one ends fixed to an outer circumferential surface of the rotary shaft 30 extending radially and have the other ends fitted with experimental boxes 20, 21, 22, 23. Gravity-adding objects are placed in each of the experimental boxes 20 to 23 and are rotated by the motor in the microgravitational environment.

[0087] It is to be noted that while the above example has been described with a case of the four arms 24 to 27 supporting the four experimental boxes 20 to 23, the arms may be more than four extending radially, for example, eight arms supporting eight experimental boxes, and the number of pieces thereof may be set appropriately according to the kind, size, etc. of the experimental objects.

[0088] Figs. 11 (a) and (b) show cross sectional portions of the rotator supporting mechanism of the fifth embodiment shown in Fig. 10, wherein Fig. 11(a) is a cross sectional view seen from arrows on line E-E of Fig. 10 and Fig. 11(b) is a cross sectional view seen from arrows on line F-F of Fig. 10. In Fig. 11(a), the upper fixing member 31 of the cylindrical shape is fitted to the casing 10 and an annular coil as the magnetic bearing 11 is arranged in the upper fixing member 31. The rotary shaft 30 passes through a central portion of the mechanism. In Fig. 11(b), four vibration sensors 4 are arranged on the orthogonal X and Y coordinates in the lower fixing member 32 and, below the vibration sensors 4, the bias control magnetic bearing 35b is arranged being fitted to the lower fixing member 32. It is to be noted that vibration sensors 3 and the bias control magnetic bearing 35a are likewise arranged in the upper fixing member 31.

[0089] In the fifth embodiment constructed as mentioned above, when the rotary shaft 30 is rotated, there arise imbalances in the acceleration between each of the experimental boxes 20 to 23 due to weight imbalances in the experimental objects. Thus, the rotary shaft 30 vibrates and the vibration or displacement of the rotary shaft 30 is detected by the plurality of vibration sensors 3, 4 arranged on the X and Y axes in the both end portions of the rotary shaft 30, as described in the example of Figs. 1 and 2. Signals of the vibration or displacement of the rotary shaft 30 detected by the vibration sensors 3, 4 are inputted into a control unit, as will be described below, and the control unit performs a control such that, if the gap between the rotary shaft 30 and the sensor varies, then the electric current of the coil existing at the corresponding position of the gap so varied is controlled so as to return the varied gap to the original state to thereby actively control the vibration.

[0090] On the other hand, while no vibration occurs, the rotary shaft 30 needs to be supported making no contact with the bearing portion and it is so arranged that the coils of the bias control magnetic bearings 35a, 35b are supplied with exciting current to thereby continuously hold the rotary shaft 30 at the central position of the mechanism. In the example shown in Fig. 1, it is the magnetic bearings 11, 12 effecting the active vibration control that holds the rotary shaft 30 centrally, and thereby the bias control and the active vibration control of the rotary shaft 30 are performed at the same time. For this reason, however, the rotary shaft 30 is supported strongly by the magnetic force generated by the electric current for the bias control and, even if the vibration is very small, it easily spreads to the casing 10 side via the magnetic bearings and achievement of an effective vibration control of such a very small vibration by the magnetic bearings has been difficult.

[0091] Thus, in the present fifth embodiment, as a first means, in order for the bias control magnetic bearings 35a, 35b to hold the rotary shaft 30 at the central position, the magnetic bearings 35a, 35b are supplied with a constant exciting current for holding the position of the rotary shaft 30. Then, if vibration occurs in the rotary shaft 30, only the active vibration control magnetic bearings 11, 12 are controlled such that the magnetic force of the coils of the magnetic bearings 11, 12 existing at the position corresponding to the vibration of the bias control magnetic bearings 35a, 35b may be weakened to thereby weaken the position holding force for increase of the freedom. Thus, the vibration is prevented from spreading to the casing 10 side via the magnetic bearings 35a, 35b. At the same time, while the position holding force of the magnetic bearings 11, 12 is so weakened, the exciting current of the magnetic bearings 11, 12 is controlled so as to control the vibration, as described before with respect to Figs. 1 and 2.

[0092] Next, as a second means, while the bias control magnetic bearings 35a, 35b are supplied with electric current for holding the position of the rotary shaft 30, if vibration occurs in the rotary shaft 30, the magnetic bearings 35a, 35b are first controlled so that the position holding force of the magnetic bearings 35a, 35b may be weakened to thereby increase the freedom and, at the same time, the active vibration control magnetic bearings 11, 12 are controlled to likewise control the vibration.

[0093] According to the first means of the present fifth

embodiment, the bias control magnetic bearings 35a, 35b are not controlled for the vibration control but perform only the function of the position holding and the active vibration control magnetic bearings 11, 12 perform both the functions of the vibration control and the weakening of the position holding force. Thereby, even the very small vibration can be effectively controlled so as to be prevented from spreading outside of the casing 10. Also, according to the second means, the bias control magnetic bearings 35a, 35b are controlled so as to weaken the position holding force and, at the same time, the active vibration control magnetic bearings 11, 12 are controlled so as to perform the vibration control. By this means also, the vibration is prevented from spreading outside and even the very small vibration can be effectively controlled.

[0094] Figs. 12(a) and (b) are signal timing charts showing a control state with respect to the fifth embodiment, wherein Fig. 12(a) shows the example of the abovementioned first means in which the bias control magnetic bearings 35a, 35b are not controlled and Fig. 12(b) shows the example of the second means in which the bias control magnetic bearings 35a, 35b are controlled. Figs. 12(a) and (b) show representatively the charts with respect to one coil only out of coils of the active vibration control magnetic bearings 11, 12 and the bias control magnetic bearings 35a, 35b, respectively. In Fig. 12(a), (1) shows a wave shape of the vibration caused in the rotary shaft 30, wherein So shows a reference value, (2) shows electric current supplied to the bias control magnetic bearings 35a, 35b for the position holding, (3) shows electric current supplied to the active vibration control magnetic bearings 11, 12 for weakening the position holding force, wherein this electric current is put out while the vibration is in excess of the reference value So, (4) shows likewise electric current supplied to the magnetic bearings 11, 12 for the active vibration control while the vibration is in excess of the reference value So and (5) shows the result of the vibration control. That is, in the example of Fig. 12(a), while the bias control magnetic bearings 35a, 35b are continuously supplied with the current (2) for the position holding, the active vibration control magnetic bearings 11, 12 are supplied with the current (3) for weakening the position holding force and with the current (4) for the active vibration control. Thus, as shown in (5), if the vibration (1) exceeds the reference value So, the magnetic bearings 11, 12 weaken the position holding force and, at the same time, perform the active vibration control so that the vibration (1) may be suppressed below the reference value So.

[0095] On the other hand, in the example of Fig. 12 (b) in which (1), (2), (4) and (5), respectively, have the same meanings as described with respect to Fig. 12(a), if and while the vibration (1) exceeds the reference value So, the current (2) supplied to the bias control magnetic bearings 35a, 35b for the position holding is controlled to be reduced so that the position holding force of this portion of the vibration exceeding the reference value So may be weakened. In this state, the magnetic bearings 11, 12 are supplied with the current (4) for the active vibration control. Thus, as shown in (5), the vibration (1) in excess of the reference value So can be suppressed.

[0096] Fig. 13 is a cross sectional side view of a rotator supporting mechanism in a microgravitational rotating apparatus of a sixth embodiment according to the present invention. In the present sixth embodiment shown here, in addition to the shaft supporting structure of the rotary shaft 30 of the fifth embodiment shown in Fig. 10, active vibration control magnetic bearings 36a, 36b are added for performing a more effective vibration control. Construction of other portions is the same as that of the fifth embodiment and description thereon is omitted.

[0097] In Fig. 13, within the upper fixing member 31, the active vibration control magnetic bearings 11, 36a are arranged with the bias control magnetic bearing 35a being interposed therebetween. Also, within the lower fixing member 32, the active vibration control magnetic bearings 12, 36b are arranged with the bias control magnetic bearing 35b being interposed therebetween. The magnetic bearings 35a, 35b function to hold the position of the rotary shaft 30. The magnetic bearings 11, 36a function to actively control the vibration of the upper end of the rotary shaft 30 and the magnetic bearings 12, 36b function to actively control the vibration of the lower end of the same. As to the concrete functions of the vibration control, the same contents described with respect to Fig. 2 are applicable as they are and description thereon is omitted.

[0098] According to the sixth embodiment as described above, two pairs of the active vibration control magnetic bearings 11, 36a and 12, 36b, each bearing having the same function, are arranged with the bias control magnetic bearings 35a, 35b, respectively, being interposed between the bearings of the pair. Thereby, the vibration control of the rotary shaft 30 is balanced and a higher accuracy of the vibration control can be realized, as compared with the fifth embodiment.

[0099] Fig. 14 is a cross sectional side view of a rotator supporting mechanism in a microgravitational rotating apparatus of a seventh embodiment according to the present invention. In the present seventh embodiment shown here, in addition to the shaft supporting structure of the rotary shaft 30 of the fifth embodiment shown in Fig. 10, bias control magnetic bearings are added for a more effective position holding of the rotary shaft 30. Construction of other portions is the same as that of the fifth embodiment and description thereon is omitted.

[0100] In Fig. 14, within the upper fixing member 31, bias control magnetic bearings 35c, 35d are arranged with the active vibration control magnetic bearing 11 being interposed therebetween. Also, within the lower fixing member 32, bias control magnetic bearings 35e, 35f are arranged with the active vibration control magnetic bearing 12 being interposed therebetween. The magnetic bearings 35c to 35f function to hold the position of

the rotary shaft 30 at both ends thereof. The magnetic bearing 11 functions to actively control the vibration of the upper end of the rotary shaft 30 and the magnetic bearing 12 functions to actively control the vibration of the lower end of the same. As to the concrete functions of the vibration control, the same contents described with respect to Fig. 7 are applicable as they are and description thereon is omitted.

[0101] According to the seventh embodiment as described above, two pairs of the bias control magnetic bearings 35c, 35d and 35e, 35f, each bearing having the same function, are arranged with the active vibration control magnetic bearings 11, 12, respectively, being interposed between the bearings of the pair. Thereby, the control of the vibration and the position holding of the rotary shaft 30 is balanced and a higher accuracy of the vibration control can be realized, as compared with the fifth embodiment.

[0102] In the microgravitational rotating apparatus having the rotator supporting mechanisms of the first to the fifth embodiments as described above, while vibration occurs in the rotary shaft during the rotation due to the weight imbalances between the experimental objects placed in the experimental boxes, such vibration can be effectively controlled by the present invention. However, as the rotator is supported by the magnetic bearings, it is necessary to hold the rotary shaft floatingly making no contact with the surroundings even in the non-operation time. Thus, according to the initial state of the rotary shaft, when the magnetic bearings are supplied with power for start of the rotator, shocks of the starting time may occur so that the rotary shaft may violently hit the surroundings and strong vibration may spread outside. Hence, as a countermeasure therefor, a rotator supporting mechanism of an eighth embodiment according to the present invention will be described below.

[0103] Fig. 15 is a cross sectional side view of a rotator supporting mechanism of the eighth embodiment. In Fig. 15, within a casing 10, there are provided recess portions 10a, 10b projecting outwardly from upper and lower outer walls of the casing 10. A cylindrical upper fixing member 31 and a cylindrical lower fixing member 32 are fixedly fitted in the recess portions 10a, 10b, respectively.

[0104] A vibration sensor 3, a magnetic bearing 11 and a thrust magnetic bearing 33 are arranged within the upper fixing member 31. A motor 34, a magnetic bearing 12 and a vibration sensor 4 are arranged within the lower fixing member 32. Also, as will be further described later, elastic support mechanisms 135a, 135b are provided in the upper and lower fixing members 31, 32, respectively, for an elastic support of a rotary shaft 30. The vibration sensors 3, 4 are provided in the same arrangement as the example shown in Fig. 1(c).

[0105] The rotary shaft 30 is arranged coaxially with the cylindrical upper and lower fixing members 31, 32. An upper end of the rotary shaft 30 is supported to the upper fixing member 31 by the magnetic bearing 11 and the thrust magnetic bearing 33 as well as elastically by the elastic support mechanism 135a. Also, a lower end of the rotary shaft 30 is supported to the lower fixing member 32 by the magnetic bearing 12 as well as elastically by the elastic support mechanism 135b.

[0106] The rotary shaft 30, while being supported as mentioned above, is driven rotationally by the motor 34 fitted to the lower fixing member 32. Like in the example of Fig. 1, four arms 24 to 27 have their one ends fixed to an outer circumferential surface of the rotary shaft 30 extending radially and have the other ends fitted with experimental boxes 20 to 23.

[0107] Fig. 16 is a cross sectional view seen from arrows on line G-G of Fig. 15 for explaining the elastic support mechanism 135a. In Fig. 16, the cylindrical upper fixing member 31 is fitted to the casing 10 and the rotary shaft 30 is arranged centrally therein by being supported to the upper fixing member 31 via the elastic support mechanism 135a. The elastic support mechanism 135a comprises a bearing 138a on an inner side thereof, a ring-like supporting main body 136a on an outer side thereof and four springs 137a arranged around the supporting main body 136a connecting an outer circumferential surface of the supporting main body 136a and an inner circumferential surface of the upper fixing member 31. Thus, the rotary shaft 30 is supported rotatably by the elastic support mechanism 135a and, at the same time, supported elastically movably relative to the surroundings by the springs 137a.

[0108] It is to be noted that a spring constant of the springs 137a of the elastic support mechanism 135a is selected to be a minimum value to be able to support the rotary shaft 30 at central positions of the magnetic bearings 11, 12, 33 while in a non-operation time. Also, it is necessary to employ such springs as having a weak supporting force that is smaller than the rotary shaft 30 supporting force of the magnetic bearings 11, 12 so that, when vibration occurs in the rotary shaft 30, the vibration may not spread to the casing 10 side via the springs 137a.

[0109] Fig. 17 is a cross sectional view seen from arrows on line H-H of Fig. 15 for explaining the elastic support mechanism 135b. In Fig. 17, the cylindrical lower fixing member 32 is fitted to the casing 10 and the rotary shaft 30 is arranged centrally therein by being supported to the lower fixing member 32 via the elastic support mechanism 135b. The elastic support mechanism 135b comprises a bearing 138b on an inner side thereof, a ring-like supporting main body 136b on an outer side thereof and four springs 137b arranged around the supporting main body 136b connecting an outer circumferential surface of the supporting main body 136b and an inner circumferential surface of the lower fixing member 32. Thus, the rotary shaft 30 is supported rotatably by the elastic support mechanism 135b and, at the same time, supported elastically movably relative to the surroundings by the springs 137b.

[0110] It is to be noted that, like in the case of the abovementioned springs 137a, a spring constant and a supporting force of the springs 137b are set so as to be smaller than those of the magnetic bearings 11, 12.

[0111] According to the present eighth embodiment as described above, if vibration occurs in the rotary shaft 30, while rotating, due to weight imbalances in the experimental objects, the vibration of the rotary shaft 30 is detected by the vibration sensors 3, 4 and signals thereof are inputted into the control unit 14, as shown in Fig. 2. And by the same function as that of the device shown in Figs. 1 and 2, the vibration is effectively controlled by the magnetic bearings 11, 12.

[0112] Also, in the non-operation time, both ends of the rotary shaft 30 are supported at the central position of the bearing portion by the weak supporting force of the elastic support mechanisms 135a, 135b.

[0113] Hence, even if the magnetic bearings 11, 12, 33 are supplied with electric current for start thereof, control of the magnetic bearings are smoothly carried out and influences given on the rotary shaft 30 by the shocks of the starting time can be suppressed to the minimum.

[0114] Figs. 18(a) and (b) show a rotator supporting mechanism in a microgravitational rotating apparatus of a ninth embodiment according to the present invention, wherein Fig. 18(a) is a cross sectional view taken on a substantially same line as the line G-G of Fig. 15 and Fig. 18(b) is a cross sectional view taken on line J-J of Fig. 18(a). Also, Fig. 19 is a cross sectional view of the ninth embodiment taken on a substantially same line as the line H-H of Fig. 15. In the present ninth embodiment shown in Figs. 18(a) and (b), in place of the elastic support mechanisms 135a, 135b constructed to support the supporting main bodies 136a, 136b by the springs 137a, 137b, the support mechanisms are constructed so as to support the supporting main bodies 136a, 136b by elastic members 140a, 140b. Construction of other portions is the same as that of the eighth embodiment shown in Figs. 15 to 17 and description thereon is omitted.

[0115] In Figs. 18(a) and (b), an elastic support mechanism 145a comprises the bearing 138a, the supporting main body 136a and a ring-like elastic member 140a. The rotary shaft 30 is supported by the supporting main body 136a having the bearing 138a and the supporting main body 136a is supported to the upper fixing member 31 via the elastic member 140a arranged around the supporting main body 136a. The elastic member 140a is made of an elastic material, such as rubber, sponge rubber or urethane, and supports the rotary shaft 30 with a small spring constant and a weak supporting force, like in the case of the springs 137a of the eighth embodiment.

[0116] In Fig. 19, an elastic support mechanism 145b, like the elastic support mechanism 145a mentioned above, comprises the bearing 138b, the supporting main body 136b and a ring-like elastic member 140b. The rotary shaft 30 is supported by the supporting main body 136b having the bearing 138b and the supporting main body 136b is supported to the lower fixing member 32 via the elastic member 140b arranged around the supporting main body 136b. The elastic member 140b is made of an elastic material, such as rubber, sponge rubber or urethane, and supports the rotary shaft 30 with a small spring constant and a weak supporting force, like in the case of the springs 137b of the eighth embodiment.

[0117] Further, not only of rubber, sponge rubber or urethane, the abovementioned elastic members 140a, 140b may be also made of a plastic material or an elastoplastic material, or they may be made by a supporting means using a fluid material, a fluid bearing, etc.

[0118] According to the ninth embodiment, the same function and effect as in the eighth embodiment can be obtained.

[0119] It is to be noted that, in the eighth and the ninth embodiments, while the example of the rotator comprising the four arms 24 to 27 and the four experimental boxes 20 to 23 has been described, the rotator supporting mechanism in the microgravitational rotating apparatus according to the present invention may be applied to such a rotator as having the experimental boxes of more than four, for example, eight experimental boxes fitted to eight arms that are fitted to the rotary shaft 30 extending radially and in this case also, the same effect can be obtained.

[0120] Also, the vibration sensors 3, 4 described in the first to the ninth embodiments may be any of sensors that can detect the vibration of the rotary shaft, such as a gap sensor, a displacement sensor, an optical sensor or a laser displacement gauge.

INDUSTRIAL APPLICABILITY

[0121] According to the present invention of the respective means (1) to (24) mentioned above, the applicability is summarized as follows:

[0122] In the invention of the means (1) above, the objects in the boxes are plants or animals, for example, and there are caused imbalances in the weight between each of the boxes. Hence, when the rotator rotates, vibration occurs due to differences in the acceleration. The control unit controls the position holding force of the bearing for holding the rotary shaft to thereby suppress displacements of the rotary shaft caused by the vibration. Thus, the vibration of the rotator, that comprises the rotary shaft, the arms and the boxes, can be controlled to be suppressed to the minimum.

[0123] In the invention of the means (2) above, if vibration occurs in the rotary shaft due to imbalances in the objects in the boxes or imbalances in the system, the vibration is detected as displacements of the rotary shaft by the vibration sensors arranged closely to the circumferential periphery of the rotary shaft and signals thereof are inputted into the control unit. The control unit detects the vibration of the rotary shaft based on these

displacement signals and controls the exciting current of the coil of the magnetic bearing so as to effect the vibration control of the rotary shaft. Thus, the vibration is controlled to be suppressed and is prevented from spreading to the surrounding environment in the space via the bearing of the rotary shaft.

[0124] In the invention of the means (3) above, the vibration sensors are fitted both to the casing side and the rotary shaft or fitted to the rotary shaft. In the invention of the means (4) above, in addition to the vibration sensors, the gap sensor or displacement sensor is provided and in the invention of the means (5) above, the optical sensor or laser displacement gauge is provided. Thus, the detection of the vibration of the rotary shaft can be done with a higher accuracy.

[0125] In the invention of the means (6) above, instead of the vibration sensors of the invention of the means (4) above, the construction is made so as to detect the vibration only by the gap sensor or displacement sensor. Hence, the construction of the sensors can be simplified according to the sensing purpose or the objects in the boxes.

[0126] In the invention of the means (7) above, if the control unit detects the vibration of the rotary shaft, it compares the vibration with the previously set vibration demand value to which the vibration as in a rotating device is to be suppressed and controls the exciting current of the coil so that the vibration may be suppressed below the demand value. Hence, bad influences given on other equipment or apparatus in the space can be avoided.

[0127] In the invention of the means (8) above, the control unit detects the vibration based on the displacements of the rotary shaft detected by the gap sensor, the displacement sensor, the optical sensor or the laser displacement gauge, compares the vibration with the spectrum demand value that is set with respect to the vibration spectrum and effects the control so as to suppress the vibration below the demand value. In the invention of the means (9) above, if the detected vibration acceleration or amplitude is in excess of the demand value, the control unit effects the vibration control so that the vibration may be suppressed below the demand value concentrically with respect to the vibration range in excess of the demand value. Thus, the vibration can be instantaneously suppressed.

[0128] In the invention of the means of (10) above, the control unit stores the information of the frequency, acceleration, amplitude, etc. of the detected vibration to be reflected on the control law of the subsequent vibration controls. In the invention of the means (11) above, the detected vibration data are compared with the previously stored data so that the cause of the vibration may be grasped and, in the invention of the means (12) above, the cause of the vibration is grasped based on the result of the comparison and learned so as to be reflected on the control law. Hence, by the learning function, the vibration control becomes more accurate.

[0129] In the invention of the means (13) above, in the control of the vibration control coil, the control unit puts out the signals of which amplitude is changed by combining the linear signal and the non-linear signal corresponding to the sizes of the displacement signals sent from the vibration sensors and the vibration control coil is controlled by the output signals so put out by the control unit. By this control, the vibration can be optimally suppressed and converged.

[0130] In the invention of the means (14) above, the bearing supporting both ends of the rotary shaft is a magnetic bearing and this magnetic bearing functions both as the rotary shaft supporting bearing and the vibration control coil. Hence, the structure of the vibration control system of the rotator is simplified and the vibration can be optimally suppressed and converged at both ends of the rotary shaft.

[0131] In the inventions of the means (15) and (16) above, the vibration control coil is divided into the coil portions. Thereby, the exciting current of the coil portion corresponding to the position where the displacement due to the vibration of the rotator is the largest is effectively controlled and thus the vibration of the rotator can be more effectively controlled.

[0132] In the invention of the means (17) above, the control unit computes the change rate and the inclination of the changes with respect to the time-wise changes in the vibration signals sent from the vibration sensors and corresponding to the sizes of the change rate and the inclination, the excitation of the vibration control coil is controlled. Hence, a higher accuracy of the vibration control can be realized.

[0133] In the invention of the means (18) above, the bias control magnetic bearing holds the rotary shaft at the central position of the rotation by the magnetic force. The vibration control magnetic bearing is controlled such that, upon occurrence of the vibration of the rotary shaft, the vibration control magnetic bearing generates a magnetic force so as to weaken the position holding force of the bias control magnetic bearing to a predetermined extent to thereby mitigate the position holding force of the rotary shaft. At the same time, the control to effect the active vibration control of the rotary shaft is carried out. Thus, the vibration caused by the stiff supporting force given by the bias control magnetic bearing is mitigated and even a very small vibration is prevented from spreading outside. Hence, the vibration can be effectively controlled.

[0134] In the invention of the means (19) above, the magnetic bearing supporting both ends of the rotary shaft is constructed by the two vibration control magnetic bearings and the bias control magnetic bearing arranged between them. Hence, like in the invention of the means (18) above, the vibration occurring in the rotary shaft can be prevented from spreading outside of the casing. Moreover, the rotary shaft has its both ends supported by the magnetic bearing having therein the two vibration control magnetic bearings that are arranged in

a good balance and thus a more effective vibration control becomes possible.

[0135] In the invention of the means (20) above, the magnetic bearing supporting both ends of the rotary shaft is constructed by the two bias control magnetic bearings and the vibration control magnetic bearing arranged between them. Hence, like in the invention of the means (18) above, the vibration occurring in the rotary shaft can be prevented from spreading outside of the casing. Moreover, the rotary shaft has its both ends supported by the magnetic bearing having therein the two bias control magnetic bearings that are arranged in a good balance and thus the position holding of the rotary shaft is ensured and a more effective vibration control becomes possible.

[0136] In the invention of the means (21) above, while the vibration control magnetic bearing is effecting the vibration control of the rotary shaft, the exciting current of the bias control magnetic bearing is controlled so as to weaken the position holding force of the rotary shaft to a predetermined extent. Thereby, the position holding force given by the bias control magnetic bearing for holding the rotary shaft is weakened and the vibration of the rotary shaft is given an increased freedom relative to the bias control magnetic bearing. Thus, the vibration is prevented from spreading to the casing side via the bias control magnetic bearing and is effectively controlled by the vibration control magnetic bearing.

[0137] In the invention of the means (22) above, the rotary shaft is supported at the central position of the rotation, even while the magnetic bearing is being supplied with no power. Also, the shaft supporting force of the elastic support mechanism is set smaller than that of the magnetic bearing. On the other hand, the shaft supporting force of the elastic support mechanism is set so as to have a minimum shaft supporting force to support the rotary shaft at the central position while the magnetic bearing is being supplied with no power and no supporting force of the magnetic bearing is being generated. Hence, the vibration occurring in the rotary shaft is prevented from spreading to the casing side via the magnetic bearing and the vibration is effectively controlled by the magnetic bearing.

[0138] In the invention of the means (23) above, the elastic support mechanism is constructed by the main body holding the magnetic bearing and the plurality of springs connecting the main body to the casing side. Also, in the invention of the means (24) above, the elastic support mechanism is constructed by the main body holding the magnetic bearing and the elastic member, made of an elastic material, connecting the main body to the casing side. Thus, the rotary shaft can be elastically supported by a simple elastic support mechanism. The elastic support may be realized not only by such an elastic material as rubber, sponge rubber or urethane but also by a supporting means using a fluid material, a fluid bearing, etc.

Claims

1. A rotator supporting mechanism in a microgravitational rotating apparatus, said rotator comprising a rotary shaft, provided within a casing of said microgravitational rotating apparatus, having its both ends or one end supported to the side of said casing by a bearing of said rotator supporting mechanism so as to be rotationally driven by a motor, a plurality of arms, extending radially, having their one ends fitted to a circumferential periphery of said rotary shaft and a plurality of boxes, fitted to the other ends of said plurality of arms, in which a gravitational, or gravity-adding, object is placed, **characterized in that** said rotator supporting mechanism comprises a control unit that controls a position holding force of said bearing for holding said rotary shaft so as to effect a vibration control of said rotary shaft.

2. A rotator supporting mechanism as claimed in Claim 1, **characterized in that** said bearing is a magnetic bearing, having a coil, fitted to said casing side being arranged closely to a circumferential periphery of said rotary shaft, said rotator supporting mechanism further comprises a plurality of vibration sensors fitted to said casing side being arranged closely to said coil as well as closely to the circumferential periphery of said rotary shaft and said control unit takes displacement signals sent from said plurality of vibration sensors to thereby detect vibration of said rotary shaft from displacement of said rotary shaft and controls exciting current of said coil so as to effect the vibration control.

3. A rotator supporting mechanism as claimed in Claim 2, **characterized in that** said plurality of vibration sensors, instead of being fitted to said casing side, are fitted both to said casing side and said rotary shaft or only to said rotary shaft and said control unit takes the displacement signals sent from said plurality of vibration sensors and controls the exciting current of said coil so as to effect an active vibration control of said rotary shaft.

4. A rotator supporting mechanism as claimed in Claim 2 or 3, **characterized in that** said rotator supporting mechanism further comprises a gap sensor or displacement sensor fitted to said casing side being arranged closely to said coil and said control unit measures a distance between said rotary shaft and said gap sensor or displacement sensor and controls the exciting current of said coil so as to effect an active vibration control of said rotary shaft.

5. A rotator supporting mechanism as claimed in Claim 2 or 3, **characterized in that** said rotator supporting mechanism further comprises an optical sensor or laser displacement gauge fitted to said

casing side being arranged closely to said coil and said control unit measures a distance between said rotary shaft and said optical sensor or laser displacement gauge and controls the exciting current of said coil so as to effect an active vibration control of said rotary shaft.

6. A rotator supporting mechanism as claimed in Claim 4, **characterized in that** said rotator supporting mechanism, instead of comprising said plurality of vibration sensors, comprises only said gap sensor or displacement sensor fitted to said casing side being arranged closely to said coil and said control unit measures the distance between said rotary shaft and said gap sensor or displacement sensor or measures the displacement of said rotary shaft to thereby detect the vibration of said rotary shaft and controls the exciting current of said coil so as to effect the active vibration control of said rotary shaft.

7. A rotator supporting mechanism as claimed in any one of Claims 2 to 4, **characterized in that** said control unit takes the displacement signals from said plurality of vibration sensors to thereby detect the vibration of said rotary shaft, compares the vibration with a predetermined vibration demand value and controls the exciting current of said coil so that the vibration may be suppressed below said vibration demand value.

8. A rotator supporting mechanism as claimed in any one of Claims 4 to 6, **characterized in that** said control unit, based on signals from any one of said gap sensor, displacement sensor, optical sensor and laser displacement gauge, measures the distance to said rotary shaft or the displacement of said rotary shaft to thereby detect the vibration of said rotary shaft, compares a spectrum of the vibration with a predetermined spectrum demand value and controls the exciting current of said coil so that the vibration may be actively suppressed below said spectrum demand value.

9. A rotator supporting mechanism as claimed in any one of Claims 2 to 8, **characterized in that** if and while said control unit detects acceleration or amplitude of the vibration in excess of a demand value, said control unit effects the vibration control of said rotary shaft so that the vibration may be suppressed below said demand value concentrically with respect to a vibration range in excess of said demand value.

10. A rotator supporting mechanism as claimed in any one of Claims 2 to 9, **characterized in that** if and while said control unit detects acceleration or amplitude of the vibration in excess of a demand value, said control unit effects the vibration control of said rotary shaft so that the vibration may be suppressed below said demand value concentrically with respect to a vibration range in excess of said demand value and at the same time stores information on frequency and acceleration or amplitude or all of these data of the vibration in excess of said demand value so that said information may be reflected on a control law that enables subsequent active vibration controls.

11. A rotator supporting mechanism as claimed in any one of Claims 2 to 9, **characterized in that** if and while said control unit detects acceleration or amplitude of the vibration in excess of a demand value, said control unit effects the vibration control of said rotary shaft so that the vibration may be suppressed below said demand value concentrically with respect to a vibration range in excess of said demand value and at the same time compares information on frequency and acceleration or amplitude or all of these data of the vibration in excess of said demand value with previously stored vibration data so that a cause of the vibration may be grasped.

12. A rotator supporting mechanism as claimed in any one of Claims 2 to 9, **characterized in that** if and while said control unit detects acceleration or amplitude of the vibration in excess of a demand value, said control unit effects the vibration control of said rotary shaft so that the vibration may be suppressed below said demand value concentrically with respect to a vibration range in excess of said demand value and at the same time compares information on frequency and acceleration or amplitude or all of these data of the vibration in excess of said demand value with previously stored vibration data so that a cause of the vibration may be grasped and learned to be reflected on a control law that is owned by said control unit to thereby enhance a control ability.

13. A rotator supporting mechanism as claimed in Claim 1, **characterized in that** said bearing comprises a bearing supporting both ends of said rotary shaft and a vibration control coil arranged around said rotary shaft with a predetermined gap being maintained from said rotary shaft, said rotator supporting mechanism further comprises a plurality of vibration sensors fitted to said casing side being arranged closely to said vibration control coil as well as being equally spaced around said rotary shaft with a predetermined gap being maintained from said rotary shaft and said control unit takes displacement signals of said gap sent from said plurality of vibration sensors and, if said displacement signals are in excess of a predetermined value, controls exciting current of said vibration control coil and, in controlling the excitation of said vibration

control coil, said control unit puts out signals of which amplitude is changed by combining a linear signal and a non-linear signal corresponding to sizes of said displacement signals so as to effect an active vibration control.

14. A rotator supporting mechanism as claimed in Claim 13, **characterized in that** said bearing supporting both ends of said rotary shaft is a magnetic bearing and said magnetic bearing not only functions to support said rotary shaft but also functions as said vibration control coil.

15. A rotator supporting mechanism as claimed in Claim 13, **characterized in that** said vibration control coil comprises coil portions divided corresponding to number and position of said plurality of vibration sensors and said control unit judges a position of the vibration sensor of which displacement signal is the largest out of the displacement signals sent from said plurality of vibration sensors and controls exciting current of that coil portion of said vibration control coil corresponding to said position of the vibration sensor.

16. A rotator supporting mechanism as claimed in Claim 14, **characterized in that** said magnetic bearing comprises coil portions divided corresponding to number and position of said plurality of vibration sensors and said control unit judges a position of the vibration sensor of which displacement signal is the largest out of the displacement signals sent from said plurality of vibration sensors and controls exciting current of that coil portion of said magnetic bearing corresponding to said position of the vibration sensor.

17. A rotator supporting mechanism as claimed in Claim 15 or 16, **characterized in that** said control unit measures time-wise changes of the displacement signals sent from said plurality of vibration sensors, computes a change rate and an inclination of the changes of the respective time-wise changes and, based on any of the computation results, enables to adjust exciting force of said magnetic bearing so as to effect an appropriate vibration control.

18. A rotator supporting mechanism as claimed in Claim 2, **characterized in that** said magnetic bearing supporting both ends of said rotary shaft comprises a vibration control magnetic bearing and a bias control magnetic bearing that effects a position holding of said rotary shaft.

19. A rotator supporting mechanism as claimed in Claim 2, **characterized in that** said magnetic bearing supporting both ends of said rotary shaft comprises two vibration control magnetic bearings and a bias control magnetic bearing arranged between said two vibration control magnetic bearings.

20. A rotator supporting mechanism as claimed in Claim 2, **characterized in that** said magnetic bearing supporting both ends of said rotary shaft comprises two bias control magnetic bearings that effect a position holding of said rotary shaft and a vibration control magnetic bearing arranged between said two bias control magnetic bearings.

21. A rotator supporting mechanism as claimed in any one of Claims 18 to 20, **characterized in that** said vibration control magnetic bearing functions only to effect the vibration control of said rotary shaft and said bias control magnetic bearing functions to effect the position holding of said rotary shaft as well as to effect a position control of said rotary shaft so as to weaken the position holding force of said rotary shaft while said vibration control magnetic bearing is effecting the vibration control.

22. A rotator supporting mechanism as claimed in Claim 2, **characterized in that** said magnetic bearing supporting both ends of said rotary shaft is supported to said casing side via an elastic support mechanism that is arranged on an outer circumferential side of said magnetic bearing and a shaft supporting force of said elastic support mechanism is set to a value smaller than a shaft supporting force of said magnetic bearing.

23. A rotator supporting mechanism as claimed in Claim 22, **characterized in that** said elastic support mechanism comprises a main body holding said magnetic bearing for supporting said rotary shaft and a plurality of springs connecting an outer circumferential surface of said main body and said casing side.

24. A rotator supporting mechanism as claimed in Claim 22, **characterized in that** said elastic support mechanism comprises a main body holding said magnetic bearing for supporting said rotary shaft and an elastic member, made of an elastic material, connecting an outer circumferential surface of said main body and said casing side.

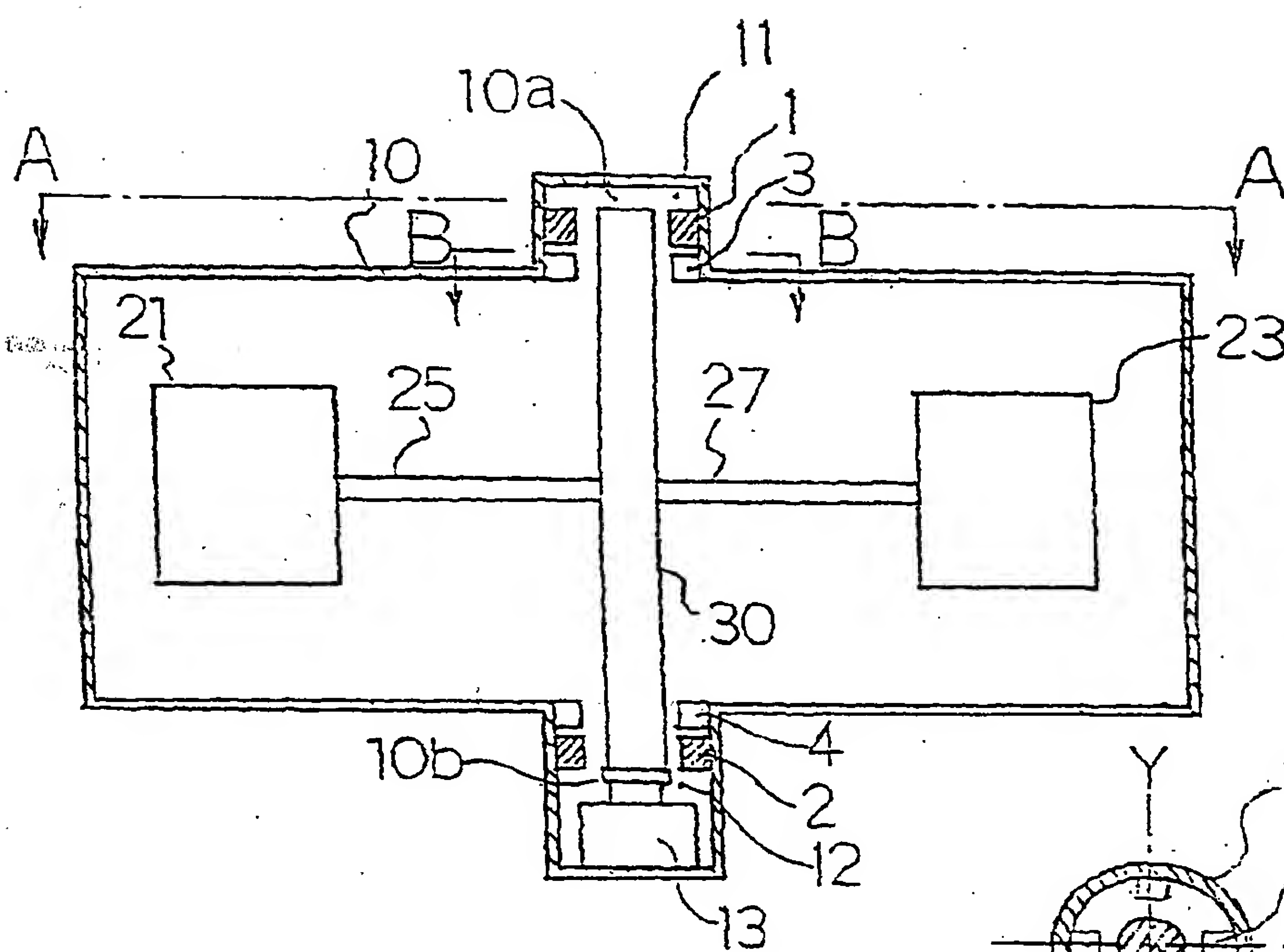


Fig. 1(a)

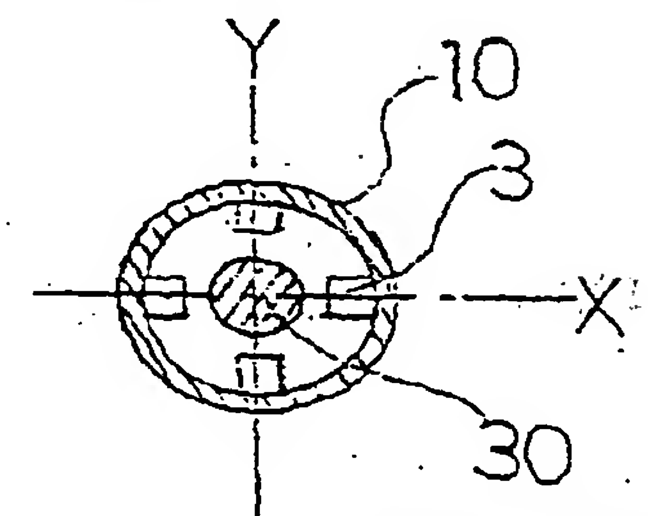


Fig. 1(c)

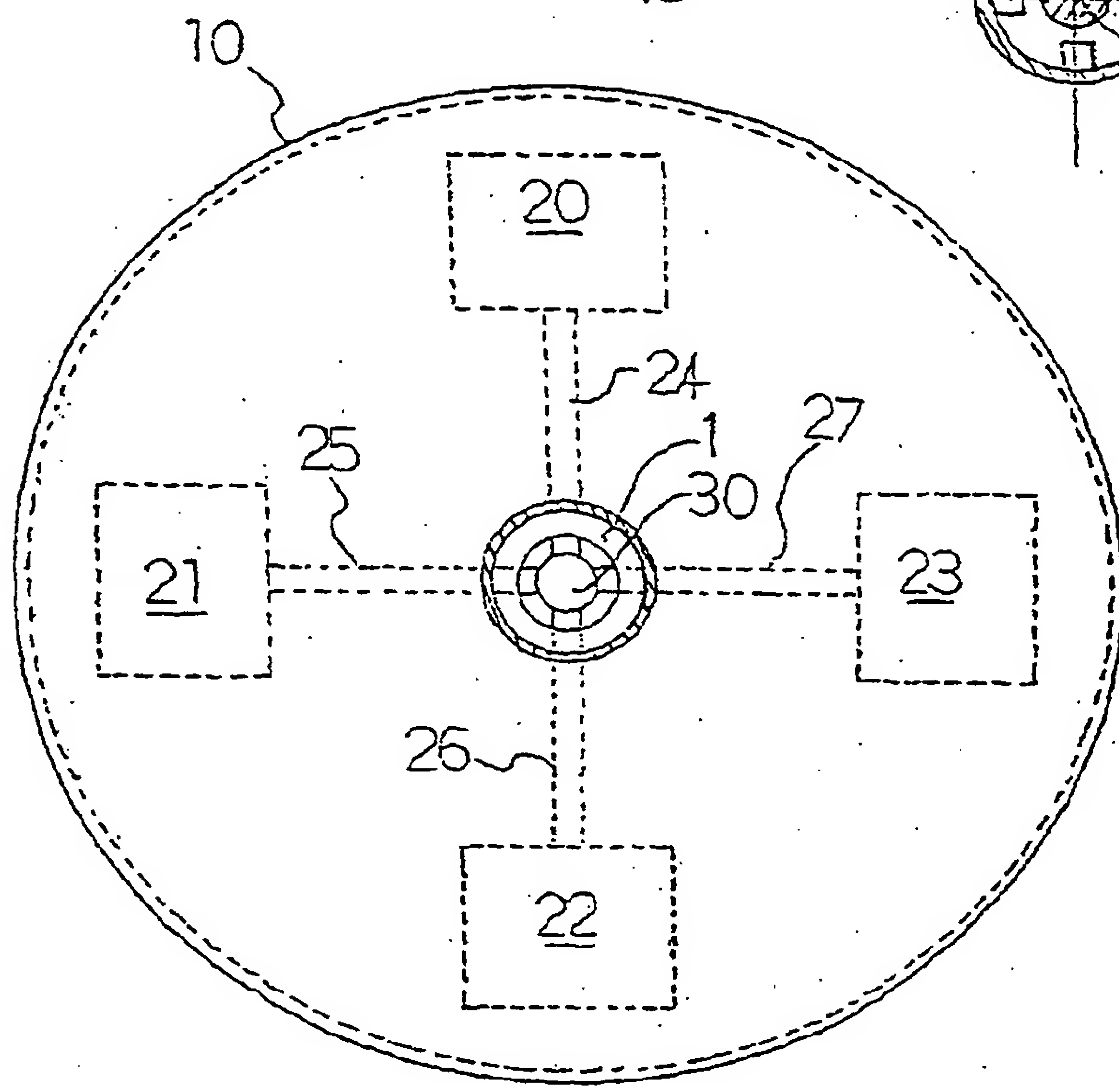


Fig. 1(b)

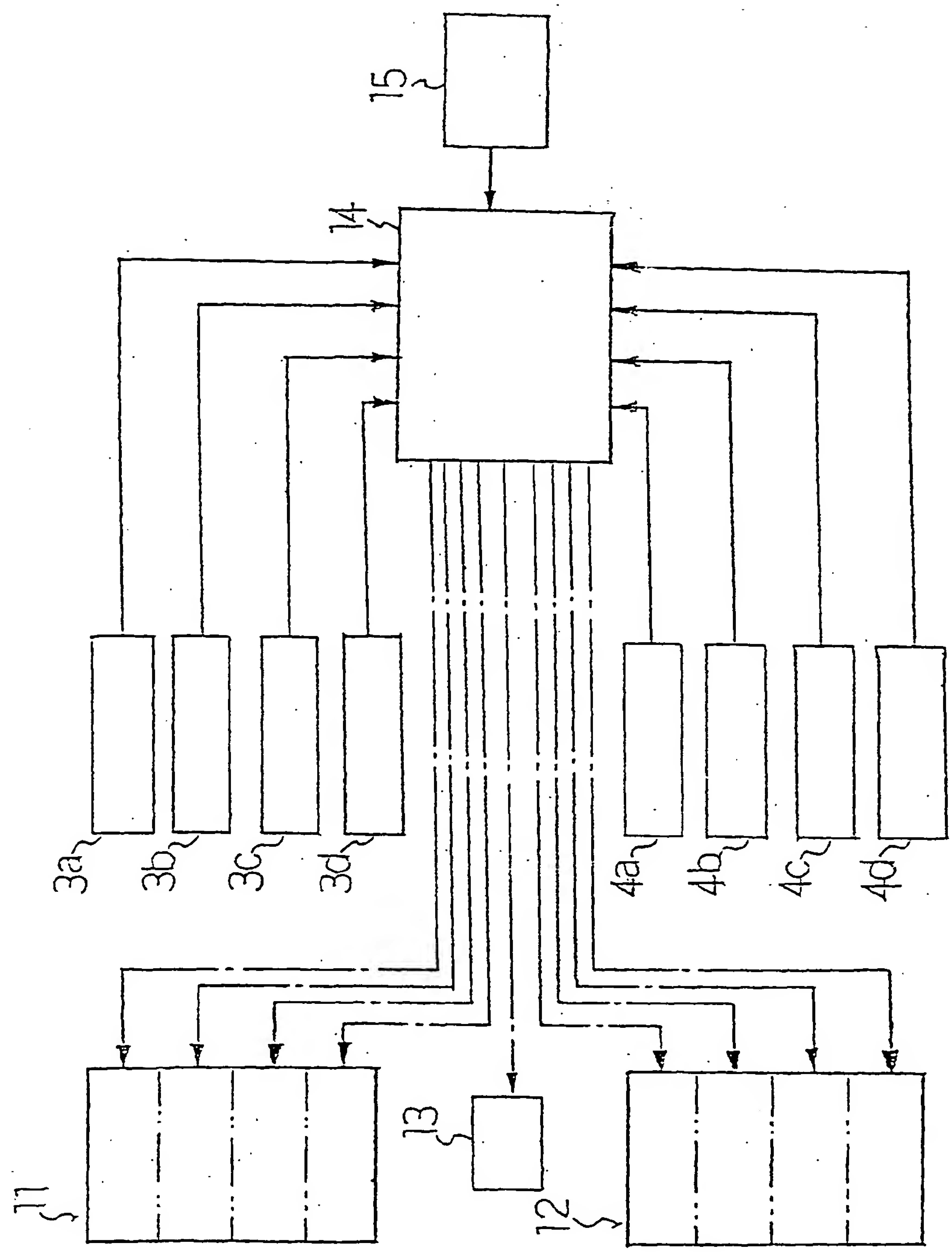


Fig. 2

Fig. 3

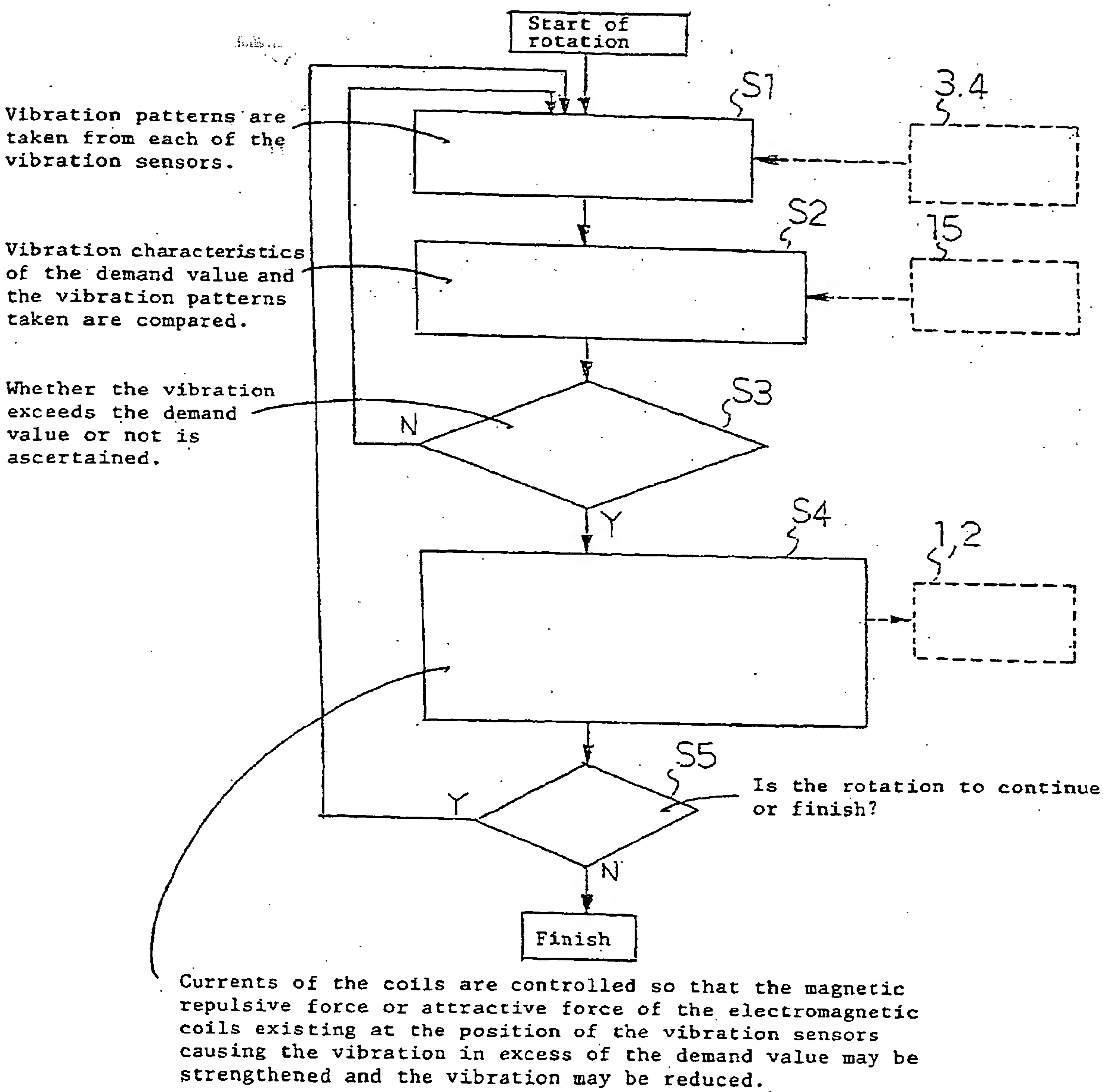

Start of rotation
S1
3.4
Vibration patterns are taken from each of the vibration sensors.
S2
15
Vibration characteristics of the demand value and the vibration patterns taken are compared.
S3
Whether the vibration exceeds the demand value or not is ascertained.
N
Y
S4
1,2
S5
Is the rotation to continue or finish?
Y
N
Finish
Currents of the coils are controlled so that the magnetic repulsive force or attractive force of the electromagnetic coils existing at the position of the vibration sensors causing the vibration in excess of the demand value may be strengthened and the vibration may be reduced.

Fig. 4

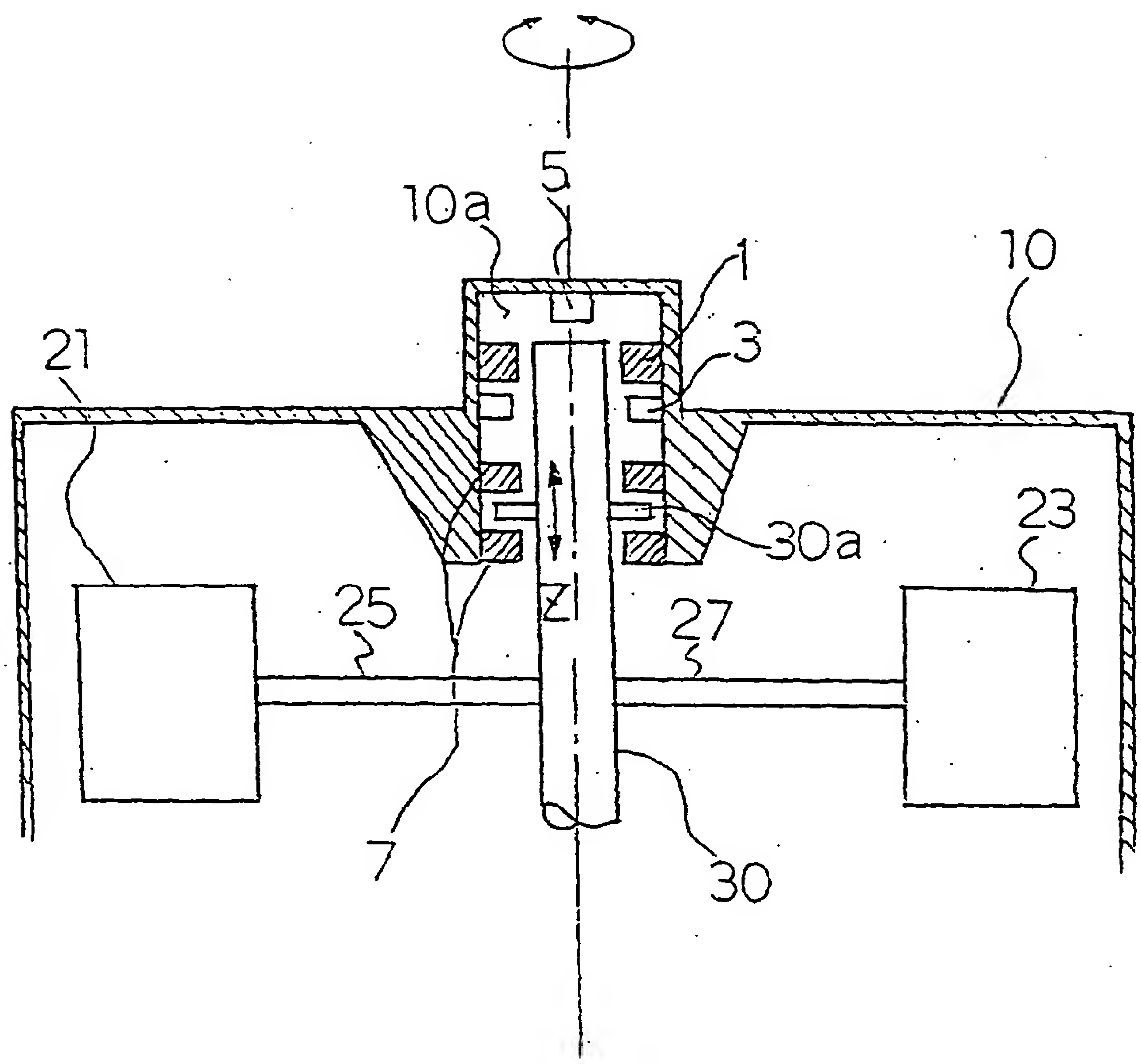


Fig. 5(a)

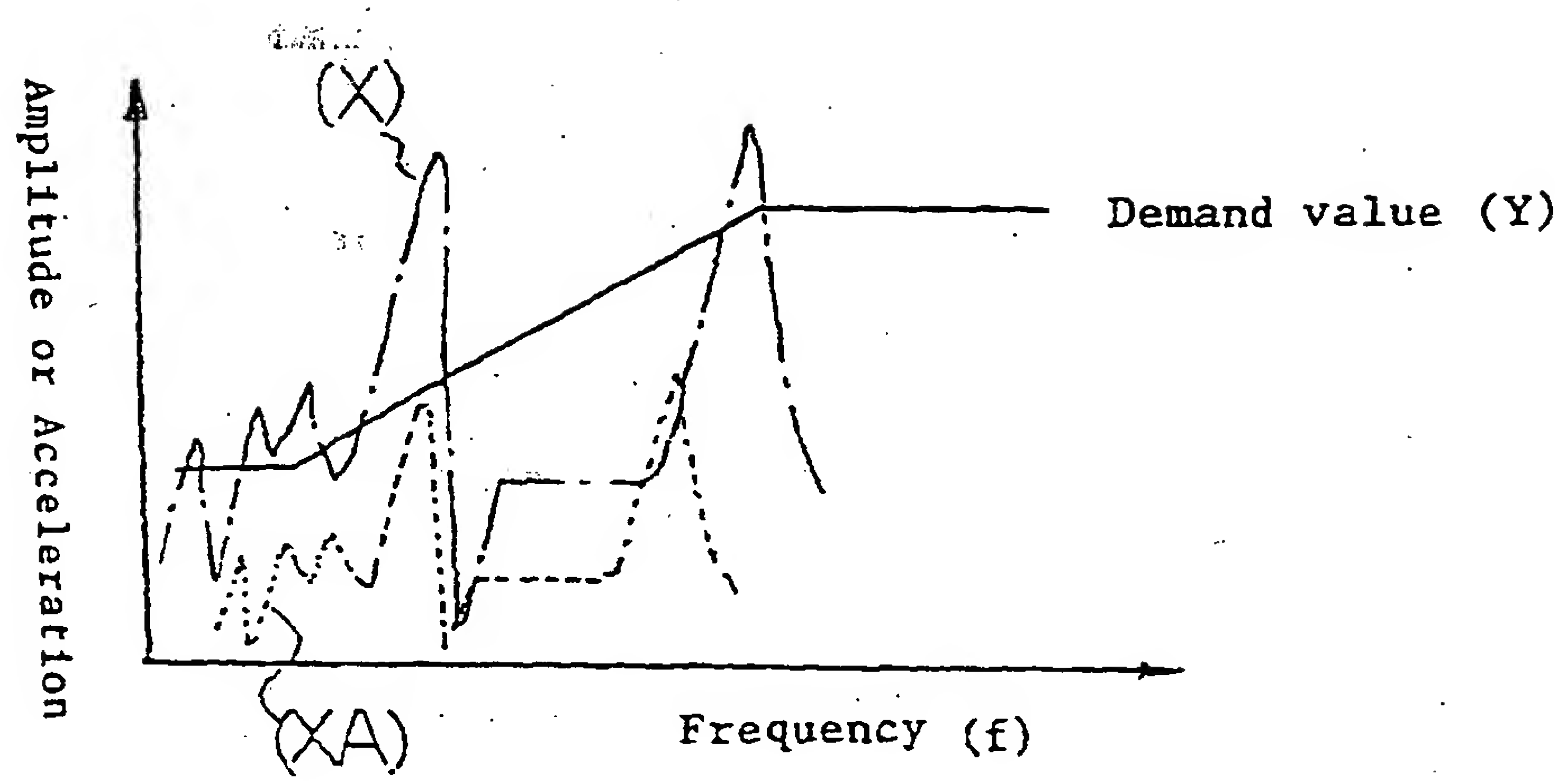

(X)
Demand value (Y)
Amplitude or Acceleration
(XA)
Frequency (f)

Fig. 5(b)

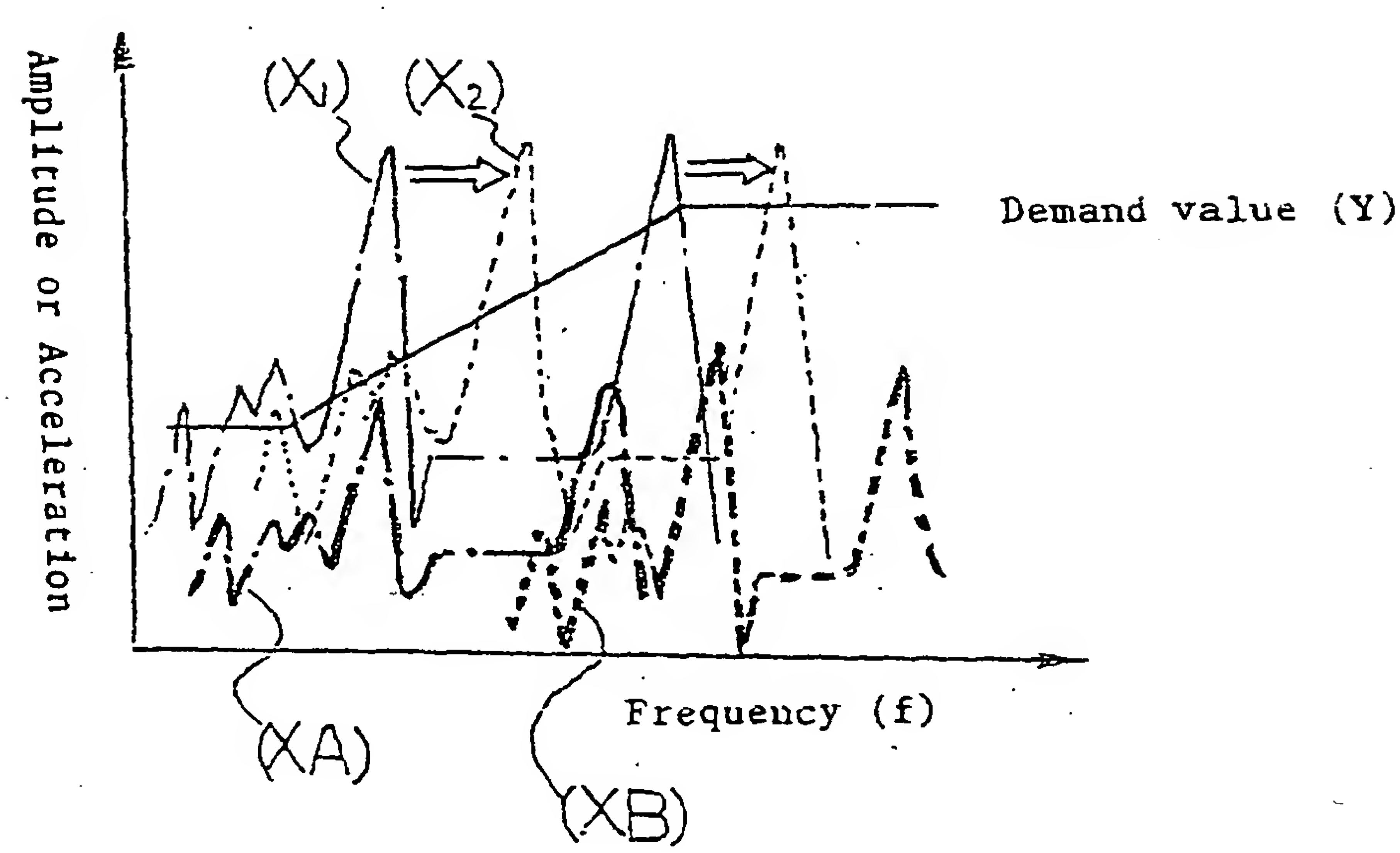

(X_1) (X_2)
Demand value (Y)
Amplitude or Acceleration
(XA)
(XB)
Frequency (f)

Fig. 6(a)

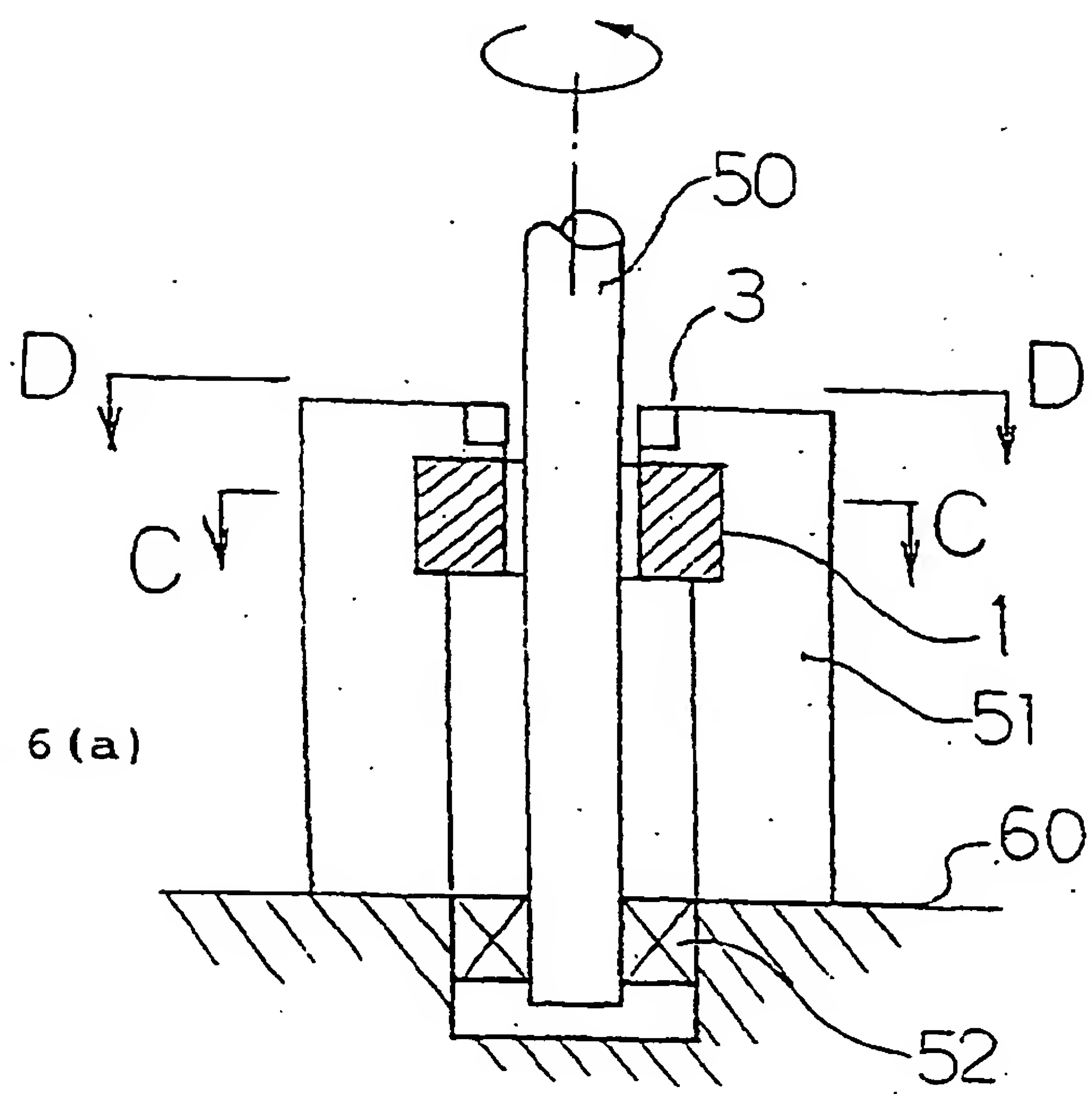


Fig. 6(b)

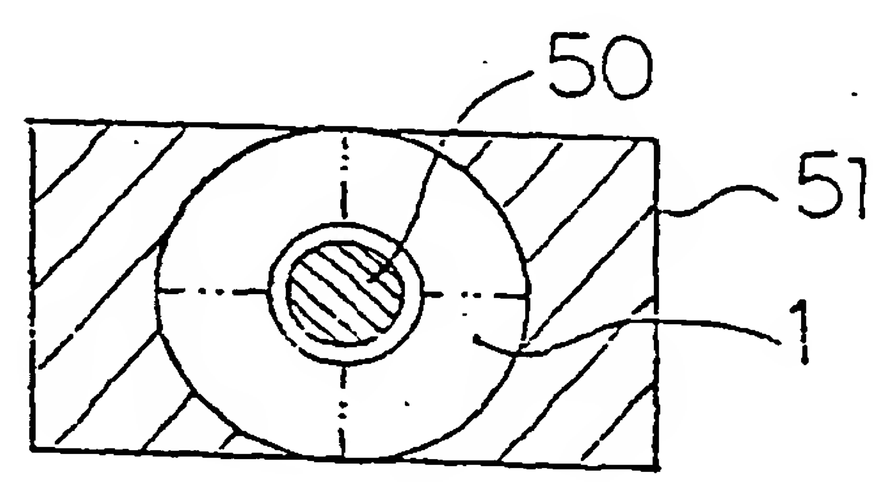


Fig. 6(c)

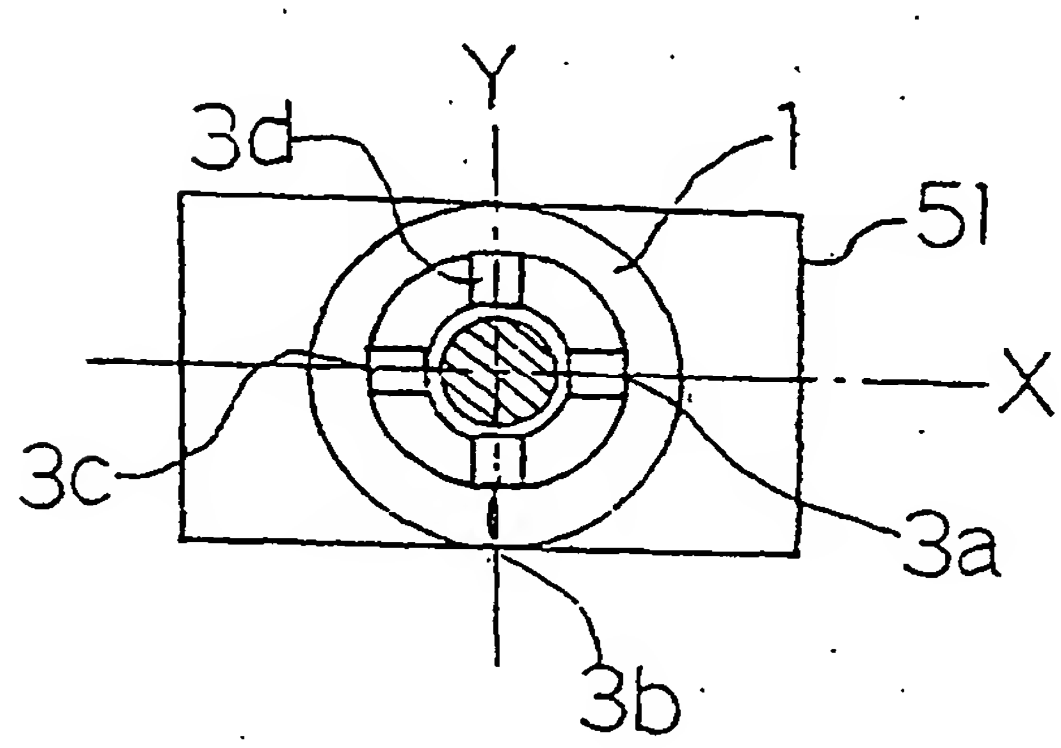


Fig. 7

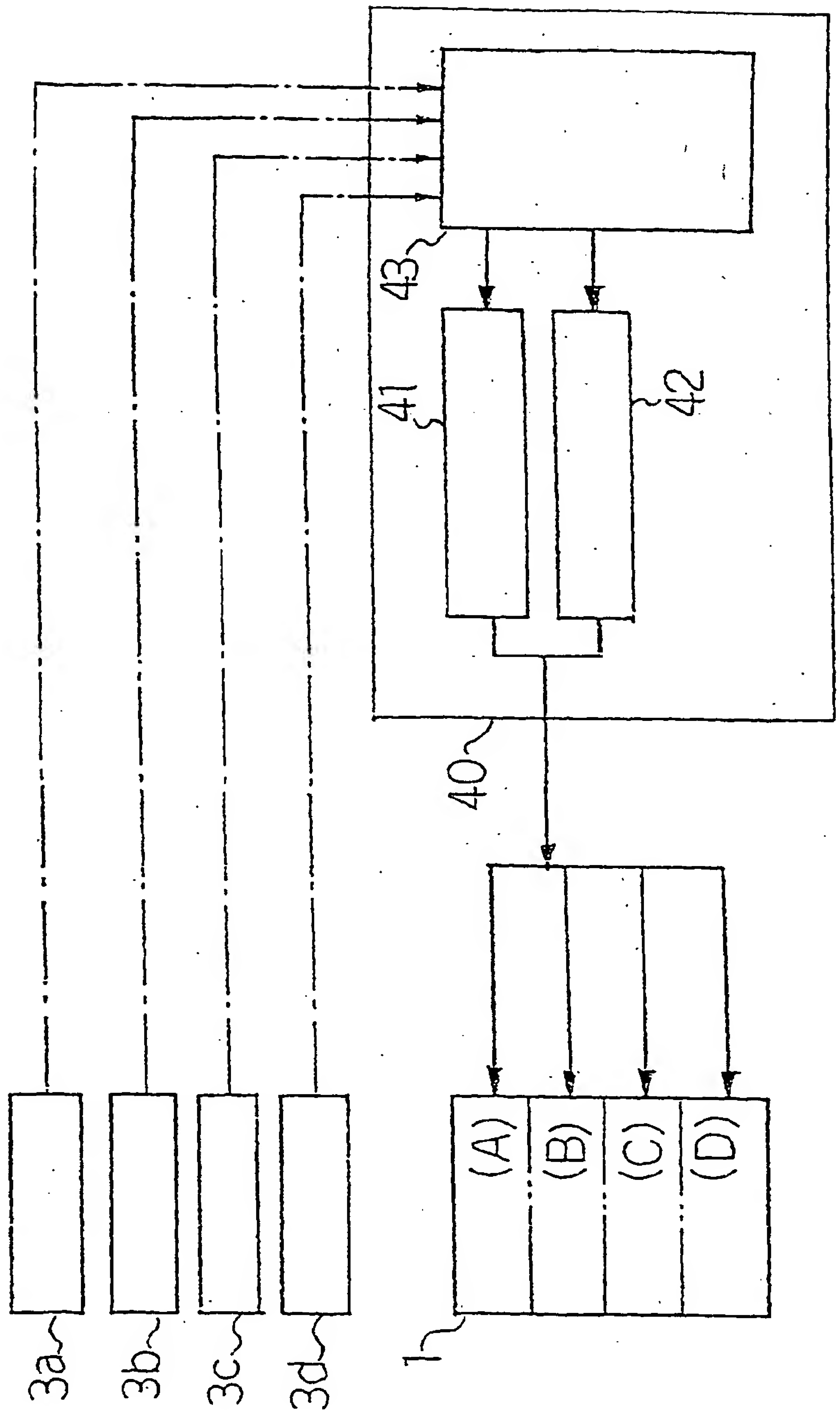


Fig. 8(a)

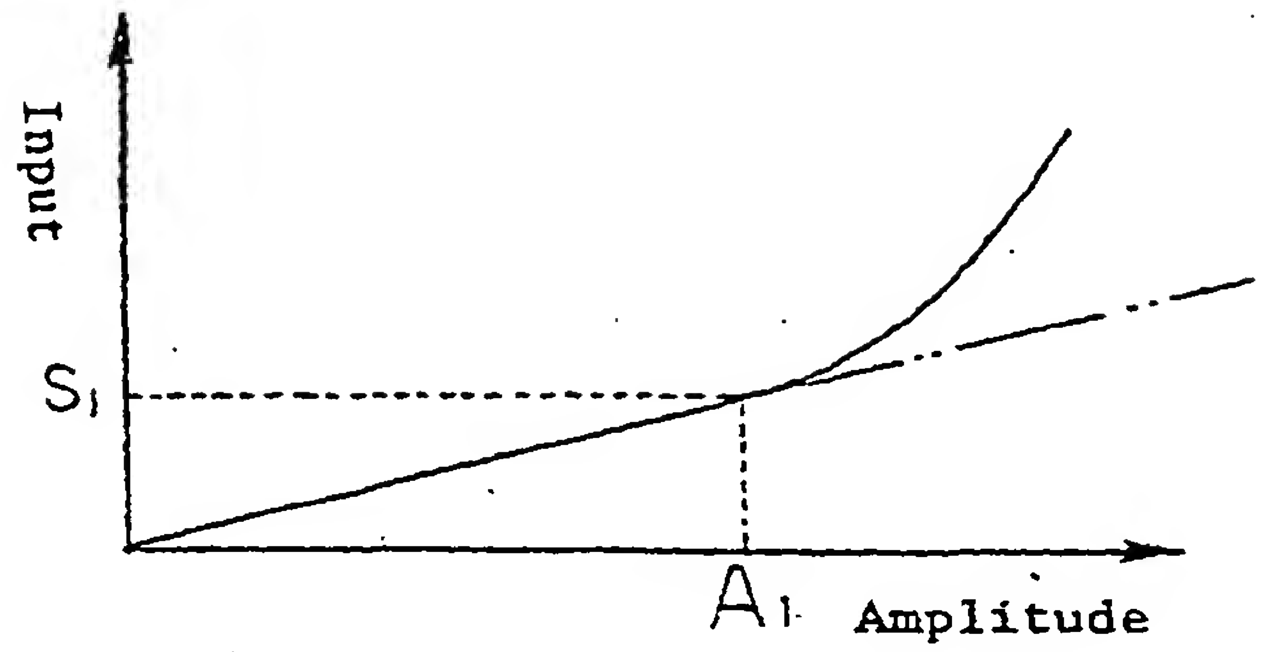


Fig. 8(b)

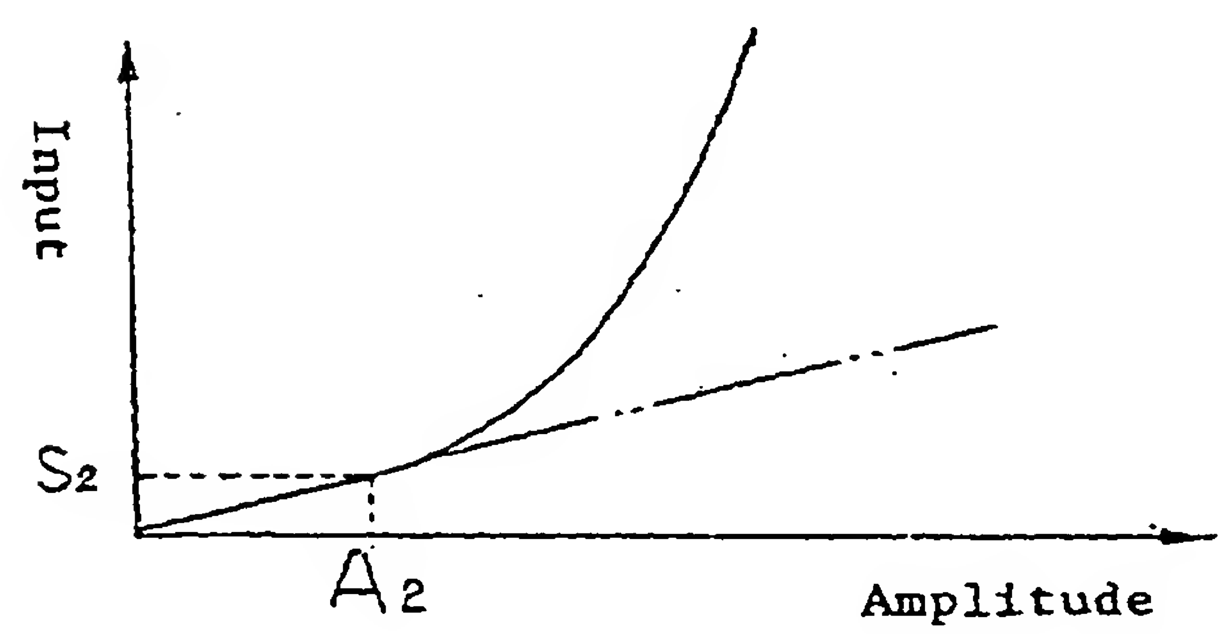


Fig. 8(c)

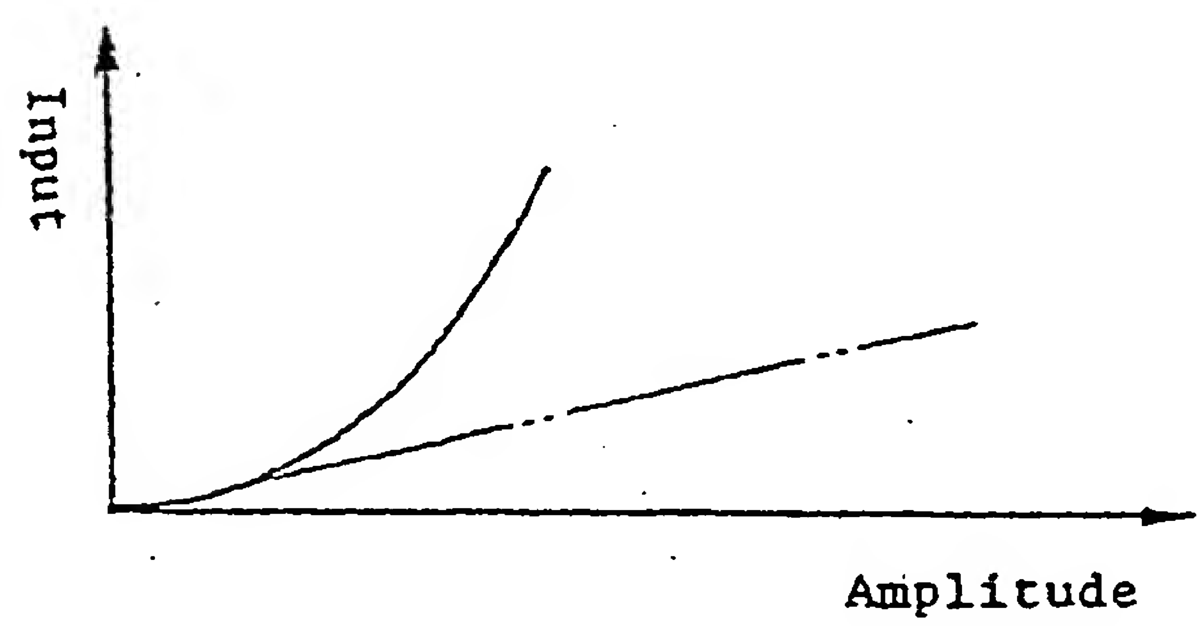


Fig. 9

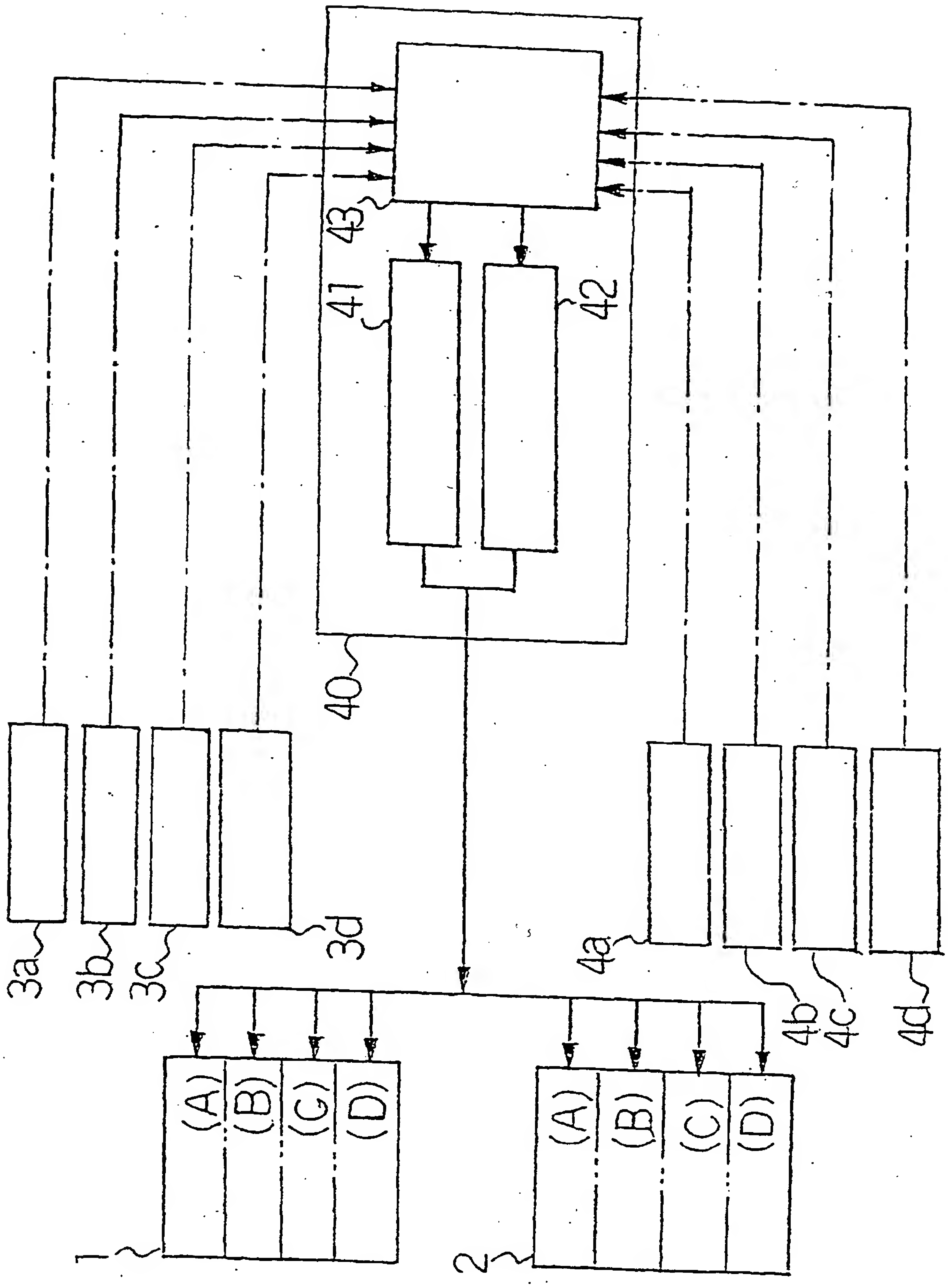
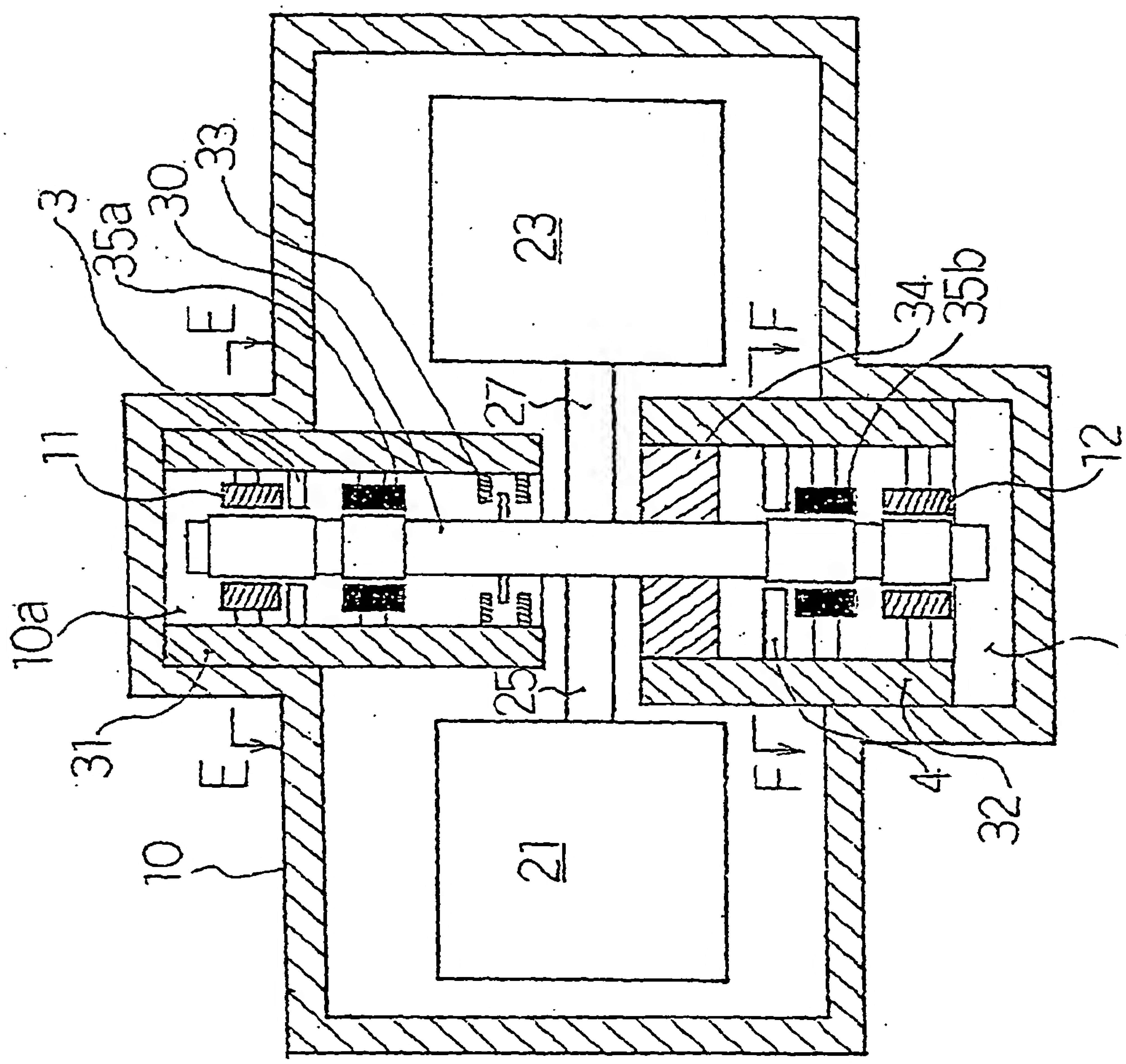


Fig. 10



BEST AVAILABLE COPY

Fig. 11(a)

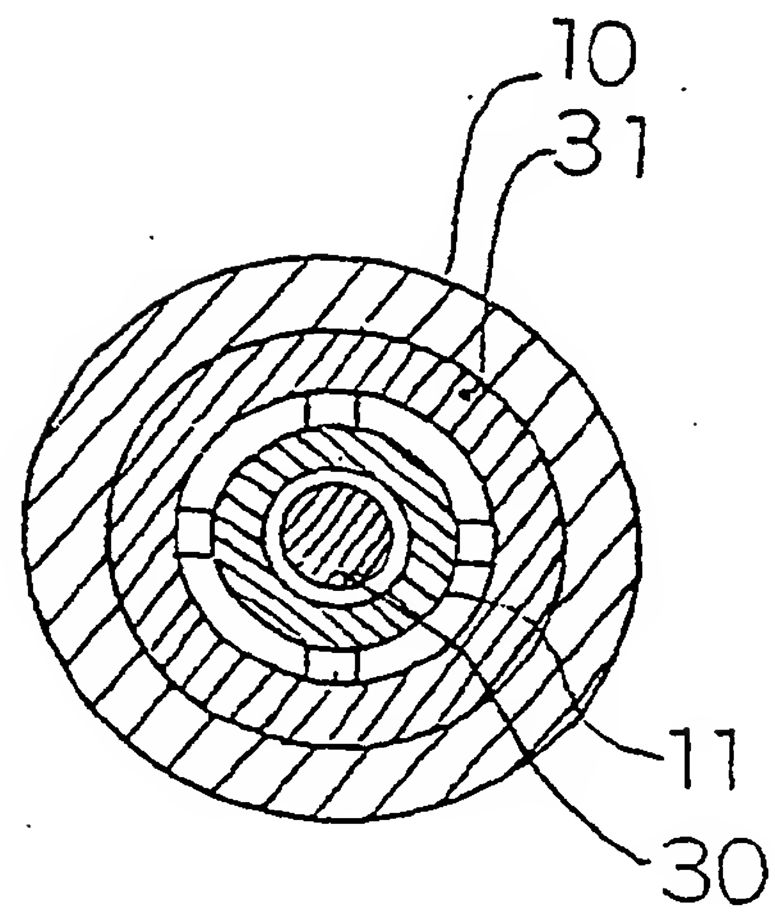


Fig. 11(b)

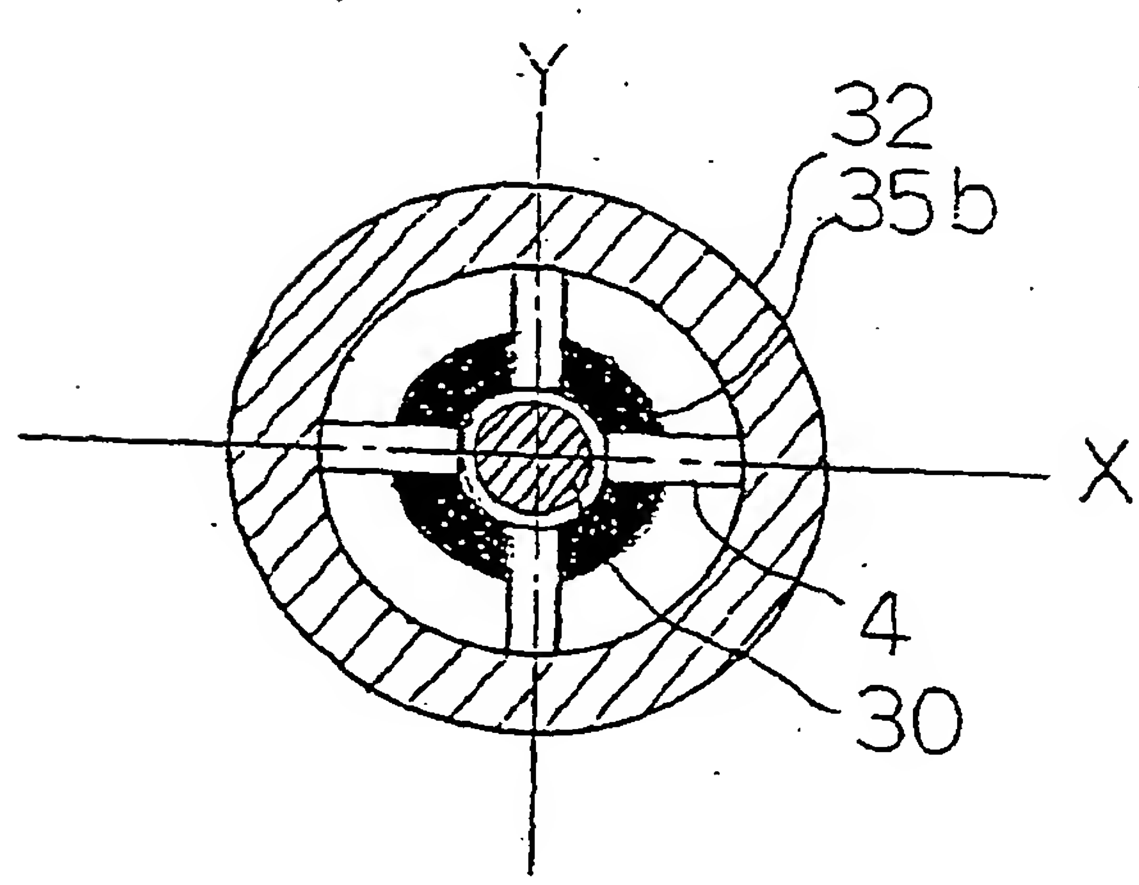


Fig. 12(b)

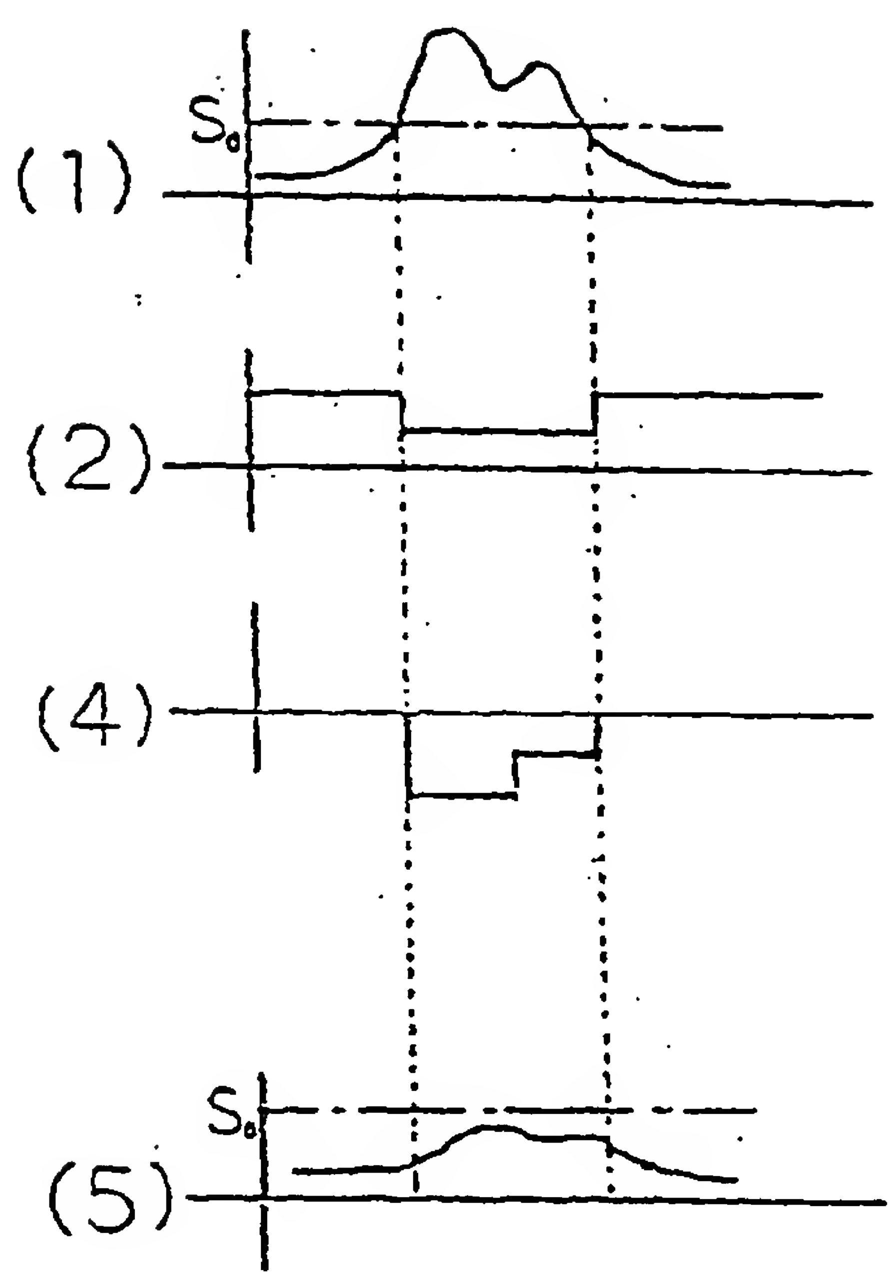


Fig. 12(a)

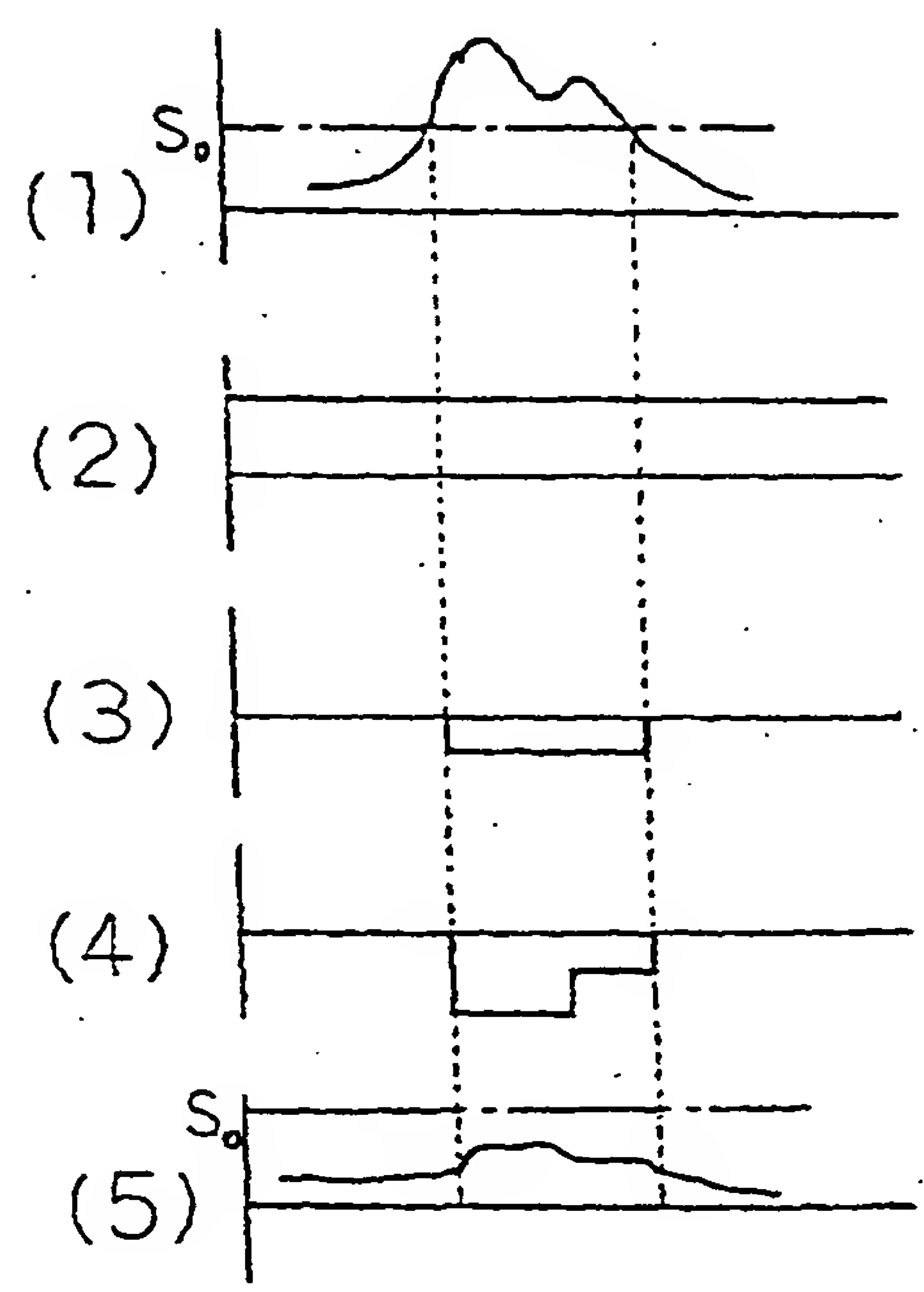


Fig. 13

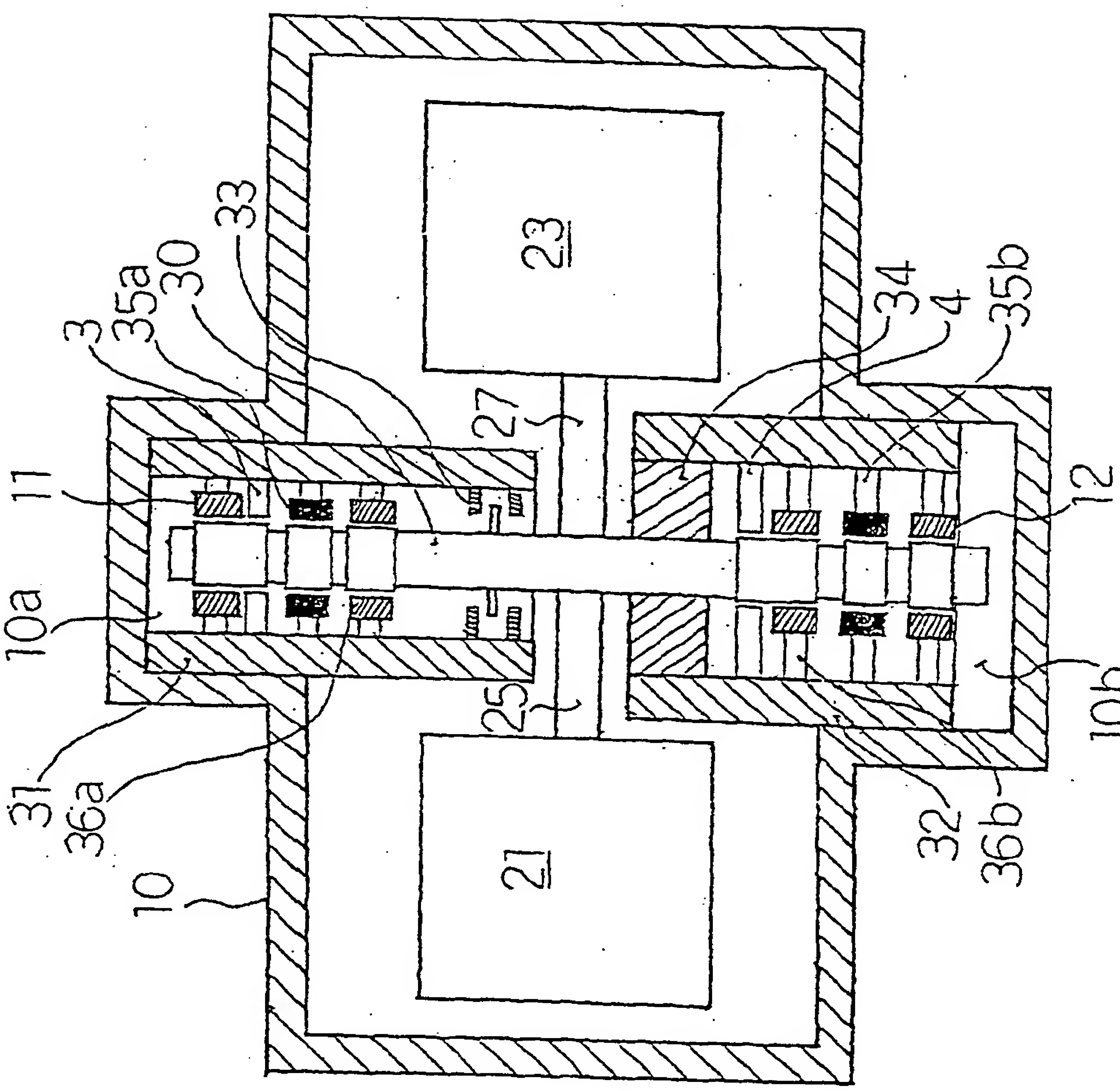


Fig. 14

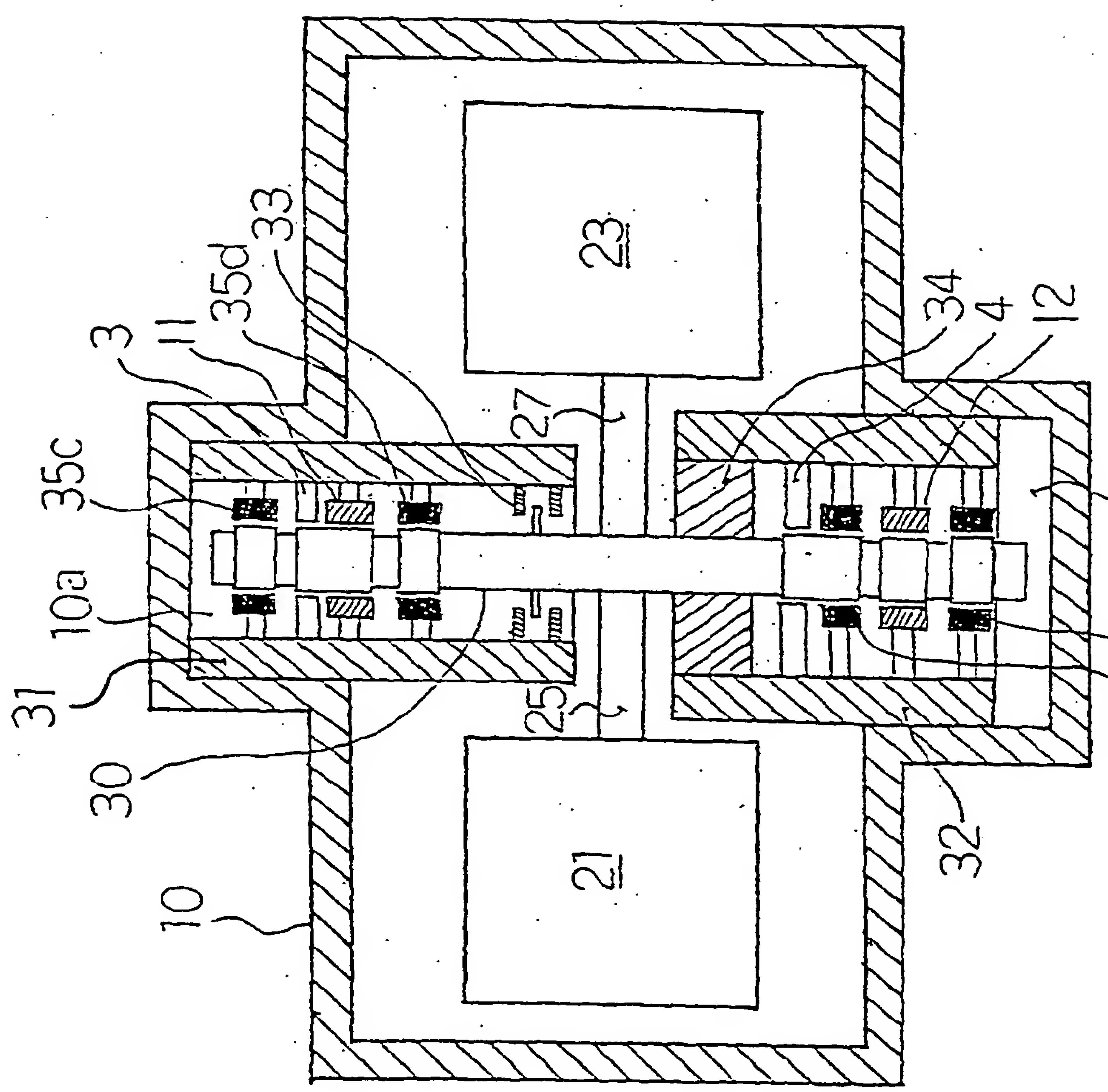


Fig. 15

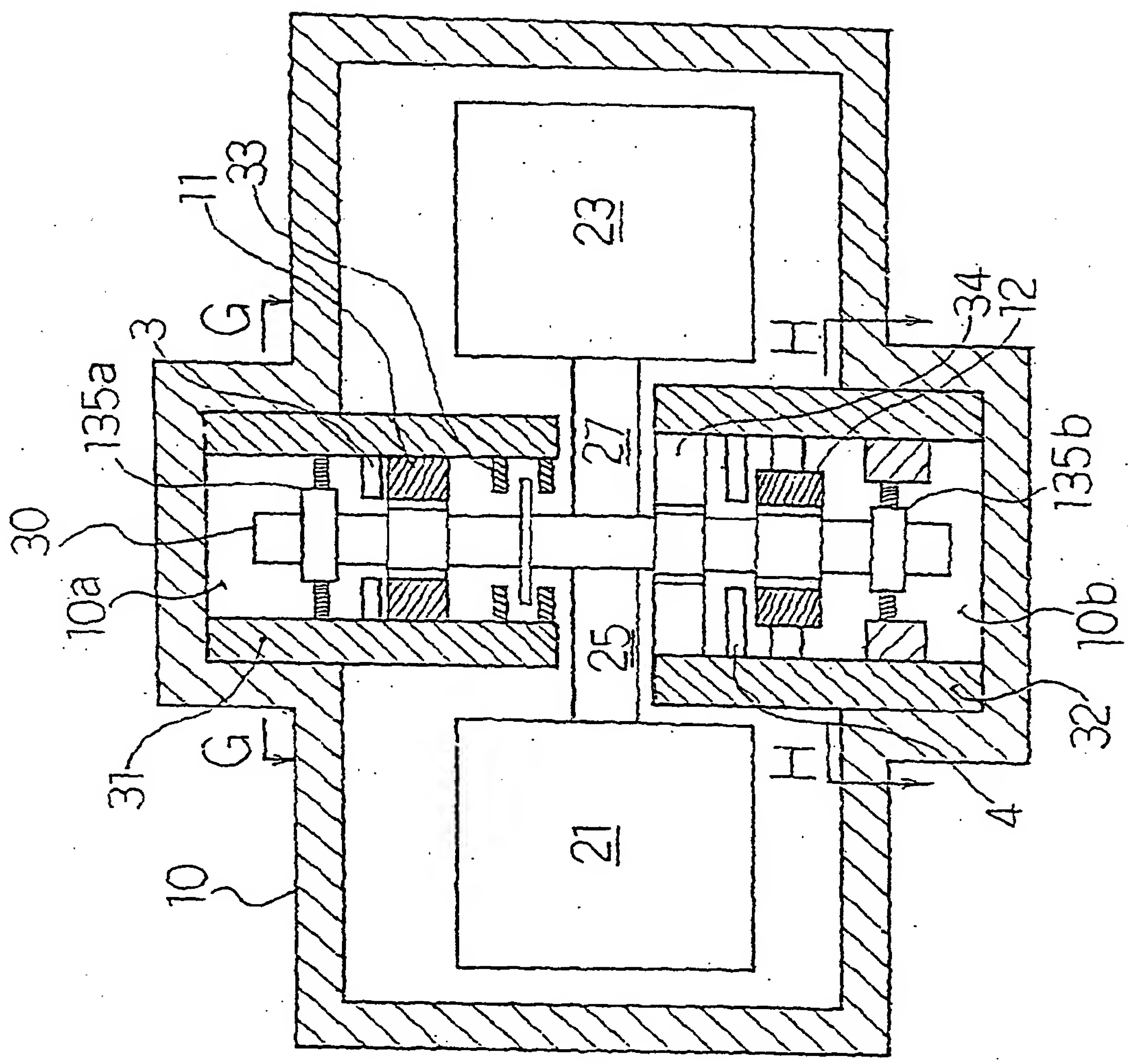


Fig. 16

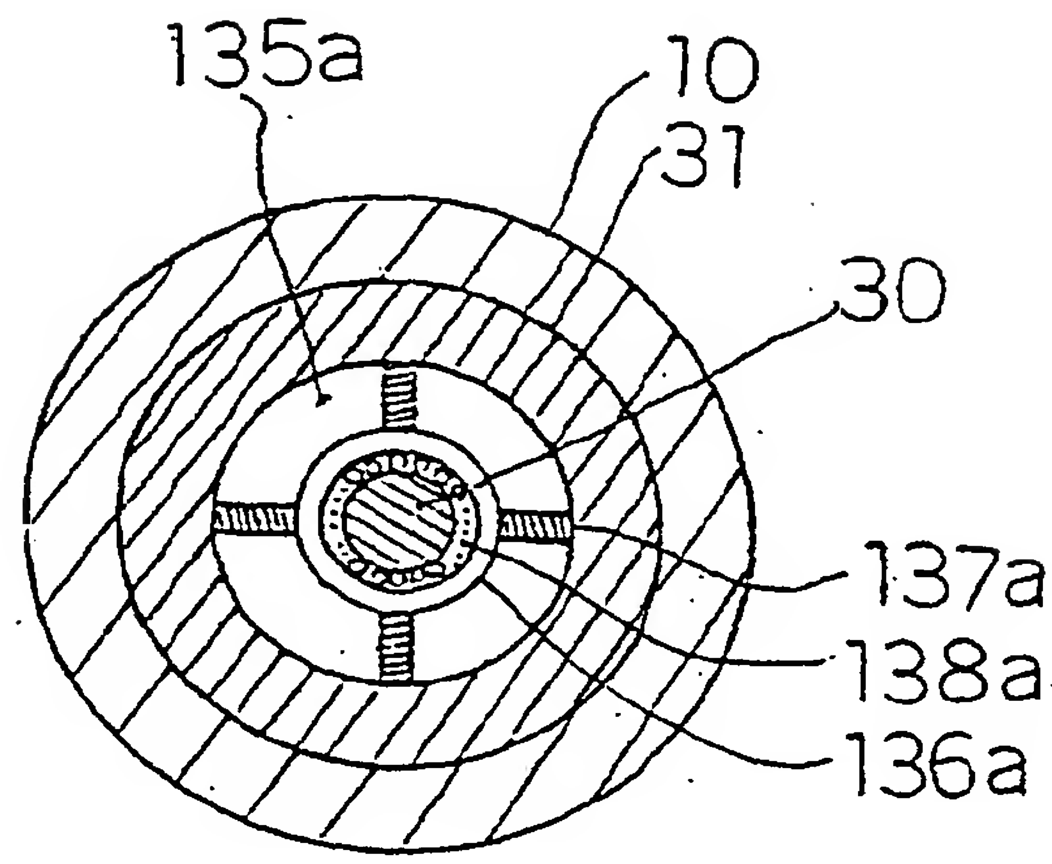


Fig. 17

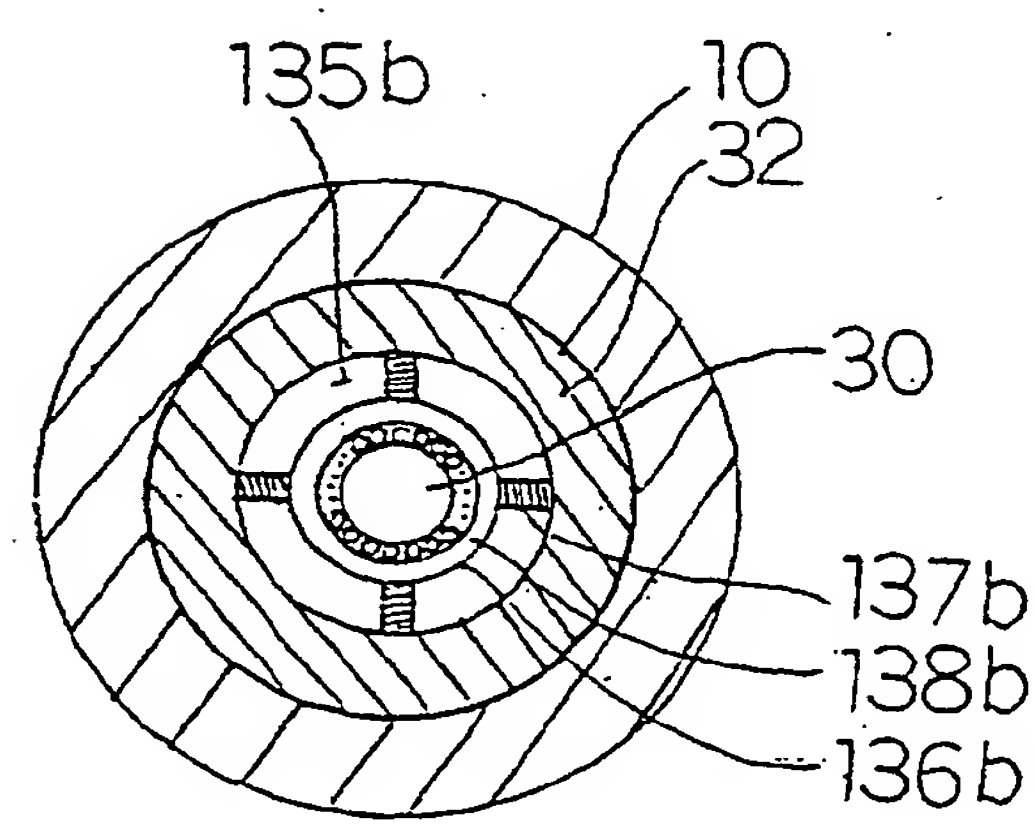


Fig. 18(a)

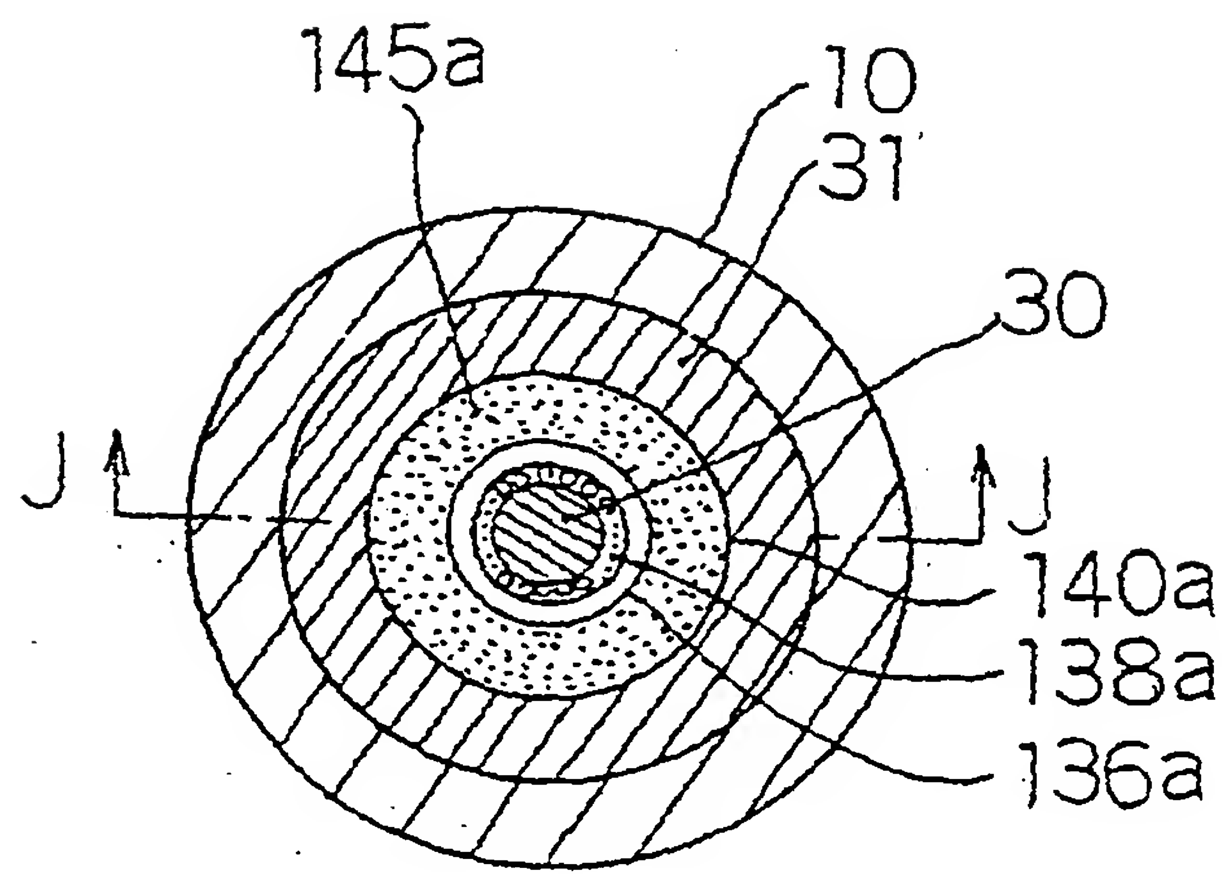


Fig. 18(b)

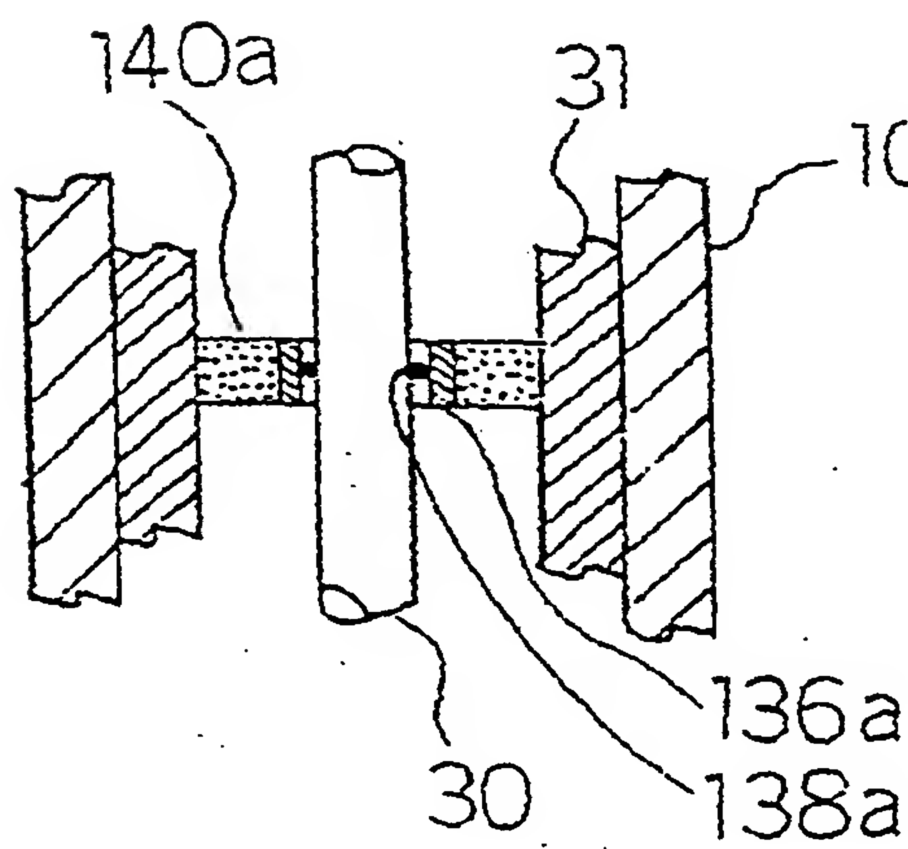


Fig. 19

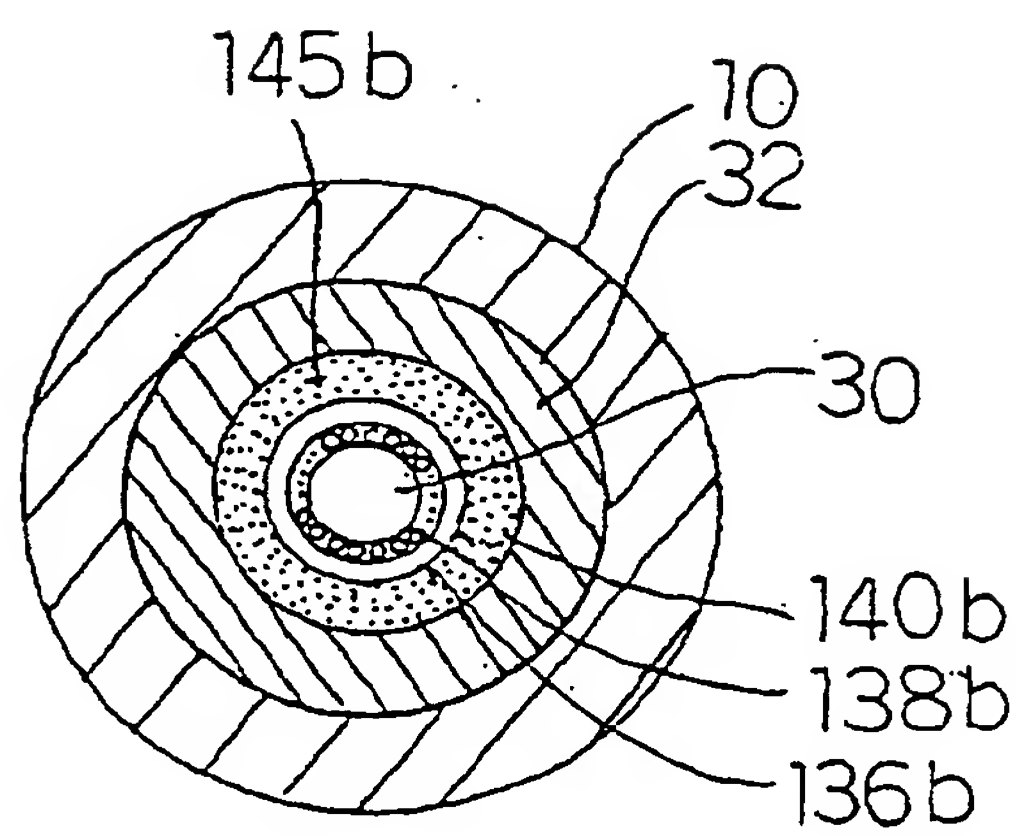
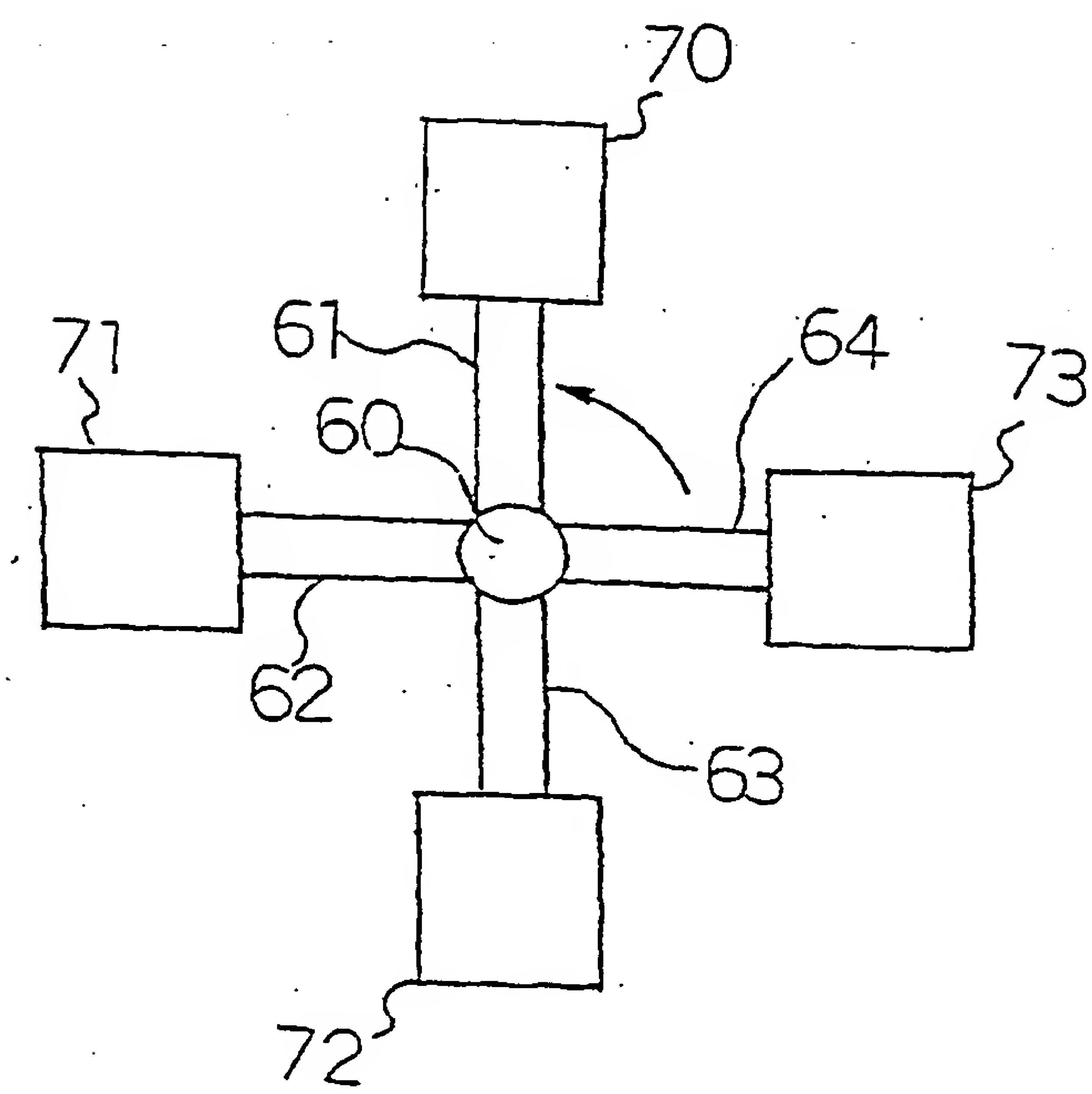


Fig. 20



INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP01/09911

A. CLASSIFICATION OF SUBJECT MATTER
Int.Cl^7 B64G 1/38, 1/66
Int.Cl^7 F16C32/04

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
Int.Cl^7 B64G 1/38, 1/66
Int.Cl^7 F16C32/04

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
Jitsuyo Shinan Koho 1926-1996 Toroku Jitsuyo Shinan Koho 1994-2001
Kokai Jitsuyo Shinan Koho 1971-2001 Jitsuyo Shinan Toroku Koho 1996-2001

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	JP 5-45204 A (Fujitsu Limited), 23 February, 1993 (23.02.1993) (Family: none)	1
A	JP 6-217663 A (Mitsubishi Heavy Industries, Ltd.), 09 August, 1994 (09.08.1994) (Family: none)	1
A	JP 2000-88627 A (TOYO ENGINEERING CORPORATION), 31 March, 2000 (31.03.2000) (Family: none)	1
A	JP 63-20297 A (Ishikawajima-Harima Heavy Ind. Co., Ltd.), 27 January, 1988 (27.01.1988) (Family: none)	1

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier document but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
18 December, 2001 (18.12.01)	15 January, 2002 (15.01.02)
Name and mailing address of the ISA/ Japanese Patent Office	Authorized officer
Facsimile No.	Telephone No.

Form PCT/ISA/210 (second sheet) (July 1992)